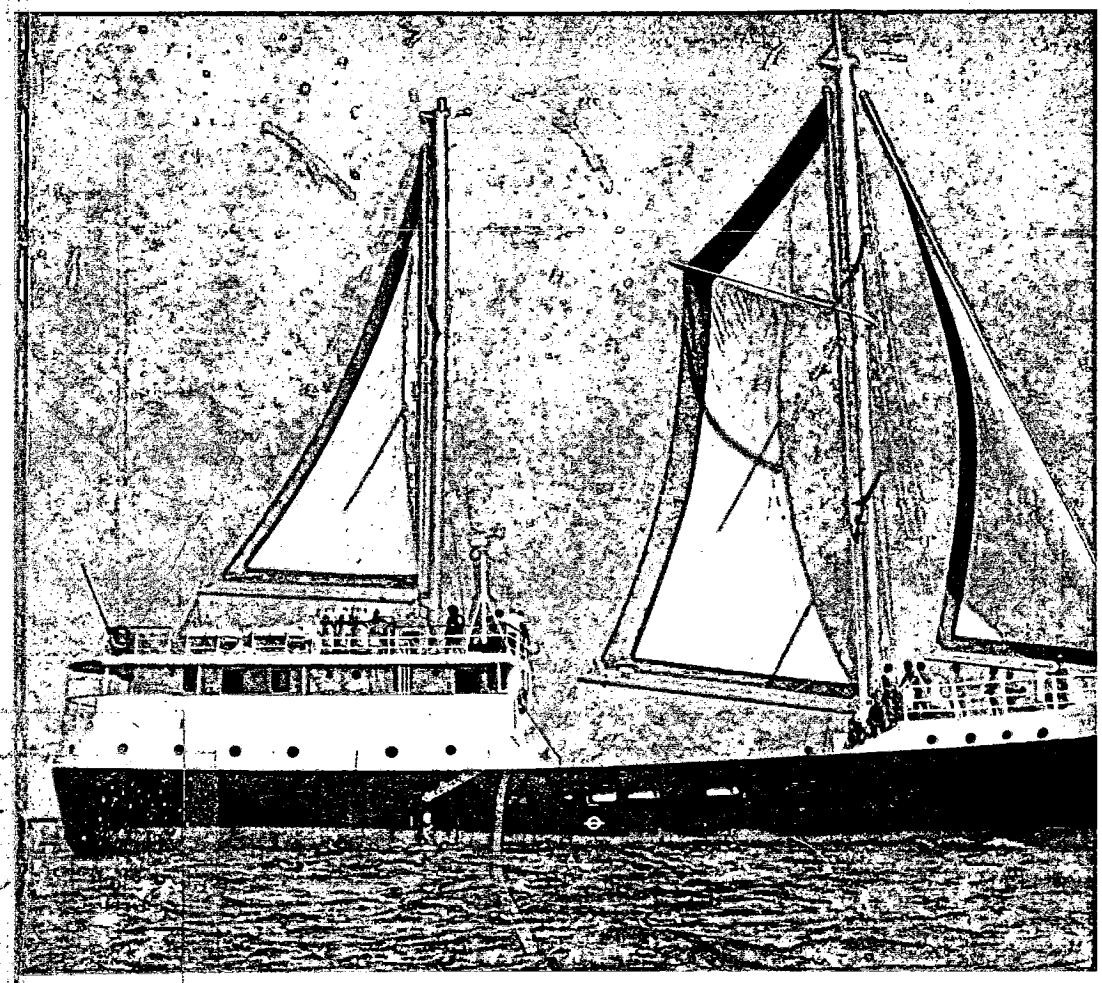
PROCEEDINGS OF REGIONAL CONFERENCE ON SAIL-MOTOR PROPULSION



ASIAN DEVELOPMENT BANK

Manila, Philippines, 18-21 November 1985

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These Proceedings are based on the discussions and papers prepared for the Regional Conference on Sail-Motor Propulsion held in Manila, Philippines on 18-21 November 1985, under the sponsorship of the Asian Development Bank.

Additional copies of this publication are available upon written request from the Information Office, Asian Development Bank, P.O. Box 789, Manila, Philippines.

FOREWORD

Since it was established in December 1966, the Asian Development Bank (ADB) has provided loans exceeding $18 billion to support nearly 800 projects in agriculture, energy, transportation, development finance, industry and the social infrastructure sectors, to promote economic and social progress in the region. With the recent admission of the People's Republic of China, approximately half of the world's population lives in the area served by the Bank.

The rapid growth of the regional economy, international trade and technological changes, particularly containerization, has placed, and will continue to place, increasing demands on the ports and shipping sectors. In these sectors, ADB has extended loans totaling $683 million mainly for port construction, modernization and rehabilitation. Also, 38 technical assistance projects totaling $6.8 million have been approved, mainly for the financing of feasibility studies and programs for institutional improvements.

To date, ADB involvement in the shipping sector totals approximately $80 million. In this regard, development finance institutions in some developing member countries have received loans from the Bank and have re-lent some of the loan proceeds to finance the acquisition of a wide range of vessel types. In 1981, the Bank made its first direct shipping loan ($1.0 million) in the Maldives, to assist in developing the interisland transport sector.

An area of more recent attention is ship repair as, for example, in Fiji and Kiribati. Experience in the improvement of navigational aids and services has been gained recently under technical assistance projects in the Maldives, Papua New Guinea and Thailand. Future activities may also be widened to include improvement of the inland waterways sector in appropriate developing member countries.

For island nations, such as Indonesia, Maldives, Philippines and the South Pacific countries, sea transportation will remain a vital mode for transporting people and goods. There is a need to modernize the domestic fleet and, in some cases, to convert existing ships so that they can carry containers. The improvement of domestic fleets must be accompanied by measures to upgrade their management and operation — including repair and maintenance, and crew training. Review of government policies which regulate domestic shipping, including scrapping policies, also needs attention. Attention also needs to be paid to new ship designs and their cargo handling equipment, which should complement the technology used in feeder ports. There is also potential to encourage the use of efficient engines and associated technology to make domestic fleets more fuel-efficient.

It is in recognition of the latter potential that the Bank organized a Regional Conference on Sail-Motor Propulsion which was held in Manila from 18 to 21 November 1985. The Conference was attended by official delegates from 20 developing member countries (DMCs) of the Bank and about 40 observers from international bodies and the private sector including the United Nations Economic and Social Commission for Asia and the Pacific, South Pacific Bureau for Economic Cooperation, Food and Agriculture Organization, International Maritime Organization, maritime classification societies, consultants, shipbuilders and others associated with the shipping industry.

I would like to extend my thanks to all the participants and observers who were able to attend the Conference. My thanks also go to the Chairman, Mr. Suleman Wiriadidjaja and the Deputy Chairman, Captain V. Basco, to the several resource persons and consultants who presented the papers and led the discussions, and to our Rapporteur, Mrs. Remedios Cruz. I also thank Mr. N. R. Collier, the Deputy Director of the Department under whose overall supervision these arrangements were made, Dr. Akatsuka, Manager of the Ports, Railways and Telecommunications Division and the Conference Coordinator, Mr. J. F. Brooks, Shipping Specialist, his colleagues and the secretarial supporting staff, for their great help during and after the Conference.

S. V. S. JUNEJA
Director
Infrastructure Department
Asian Development Bank

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PRELIMINARY CONFERENCE EVENTS

Introduction of Conference Chairman

John F. Brooks*

Distinguished delegates, ladies and gentlemen,

On behalf of Dr. Y. Akatsuka, Manager of the Ports, Railways and Telecommunications Division of the Bank and Chairman of the Coordinating Committee of this Regional Conference on Sail-Motor Propulsion, we sincerely welcome you and hope that your respective journeys to Manila were free of difficulty.

We are most grateful that your attendance exceeded our initial expectations. We recognize that your response gives us an even greater responsibility to ensure that your own expectations, questions and views are fully answered and reflected. Please be assured that we will make our best efforts in this respect, as well as assist you in any of your other needs and arrangements. A number of involved Bank Staff will constantly be on hand to comply with all such requirements. It is our earnest wish that you will judge your visit to us as fulfilling and pleasant.

In planning and preparing the Conference, we are grateful for the valued skill and experience of our Consultants, MacAlister Elliot and Partners, of the United Kingdom. We are similarly indebted to our other eminent resource persons, who will deliver the papers and guide us all in recognizing the many and interrelated considerations and inputs, which provide the necessary framework for any useful and durable development of the sail-motor concept.

The essential focus of our Conference is regional and in seeking a Chairman for this gathering we have sought the advice of the world's largest archipelagic country, Indonesia, a country which also has profound stature in the historical, continuing and successful use of sail-assisted propulsion in shipping.

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* Shipping Specialist, Asian Development Bank.

Indonesia has recognized the value and importance of continued development of wind power resources in shipping and is currently engaged, jointly with the Federal Republic of Germany, in an important experimental project, INDOSAIL. This project unites traditional skills in construction and management of interisland sailing vessels with recently developed technology, and makes full use of research skills and research facilities for efficient sailing ship design. Mr. Suleman Wiriadidjaja and his dedicated associates at the Agency for Development and Application of Technology in Jakarta are responsible in Indonesia for INDOSAIL, a project which has considerable regional as well as national value.

Chairman's Introductory Statement

Suleman Wiriadidjaja*

Distinguished delegates, ladies and gentlemen,

It is my great pleasure to have been invited by the Asian Development Bank to chair this Conference. The sail-motor concept is indeed a subject of deep and immediate interest to us in Indonesia. Later this week, it will be my privilege to accompany Mr. Peter Schenzle of the Hamburg Ship Model Basin in presenting to you the background, current status and future plans for the INDOSAIL project that has just been referred to.

In 1979, the Minister of State for Research and Technology, Prof. Dr. Ing B. J. Habibie, initiated an Indonesian-German cooperation in the development of cargo sailing vessels for the Indonesian interisland trade. Accordingly, the bilateral INDOSAIL project was started in 1980 under the joint sponsorship by the Ministries for Research and Technology of the Republic of Indonesia and the Federal Republic of Germany.

INDOSAIL is considered as a short-term effort towards the long-term objective of *Kapal Surya,* the Solar Ship as proposed by Prof. B. J. Habibie. While the INDOSAIL vessel is a wind-propelled ship with diesel auxiliary power, the Solar Ship will be completely independent of fossil energy by direct utilization, as well as by storage, of solar energy for both auxiliary propulsion and energy supply.

While hopefully contributing to the regional interests of this Conference, we also have considerable interest in learning from other ongoing projects, both within and beyond the region, together with glimpses of ongoing research in the sail-motor field, some of which confirms the value of traditional sailing methods and some of which provides fresh insights for future applications. We are also eager to profit from the question and workshop

* Assistant to the State Minister of Indonesia for Research and Technology and the Director of Technology of PT. PAL of Indonesia, Surabaya. He is a naval architect.

sessions which will, no doubt, focus on several of the practical, managerial and Government policy aspects of fuel savings in shipping.

Before commencing our Conference Program, it is my pleasant duty to introduce our Deputy Chairman, Captain Victorino Basco.

Captain Basco's work is well known to all of us in relation to his deep commitment to the maritime affairs of the region, as well as in his honorable position as Administrator of the Maritime Industry Authority of the Philippines. We are very much obliged that the experience and knowledge of Captain Basco will be available to us in helping oversee the conduct of this Conference.

Our Rapporteur, Mrs. Remedios Cruz, will have the important task of preparing notes and a transcript of each session and supervising the recording of all your questions, views and responses and will later assist the Bank in an editorial role.

Thus, we are now suitably equipped to commence our four-day voyage. To cast off the last line and set our course, it is my privilege to introduce our keynote speaker, Mr. Günther Schulz, Vice-President (Projects), of the Asian Development Bank.

Keynote Address

Günther Schulz*

Mr. Chairman, distinguished delegates, ladies and gentlemen,

The Asian Development Bank is pleased to host this Regional Conference on Sail-Motor Propulsion and is most heartened by your response to our invitation to join us and exchange views on this important aspect of fuel saving potential in the Asia and Pacific region.

Compared with other developing regions, economic growth in most countries of this region has been rapid. And for our developing members, especially those with limited resources, there is far-reaching economic value in exploring ways to allocate current expenditure on imported fuel to other sectors of the economy.

I am hopeful that the countries of the region will benefit from the sail-motor concept, as one way to readily apply low cost means of fuel saving in shipping to complement other ongoing research and development.

Among the 20 participating countries attending this Conference, archipelagic countries which rely extensively on coastal and interisland shipping for the transport of cargo and passengers are particularly likely to benefit from appropriate applications of sail assistance. Indonesia and Maldives, for example, have a very strong and continuing history in the skills associated with traditional use of sail and are well placed to apply the systems which will be discussed during the next four days.

Several Pacific island countries have sent delegates to this Conference. Non-Bank member countries in the Pacific have also expressed deep interest in the results of this gathering and we intend to provide them with copies of the Proceedings. I am particularly pleased that the Federated States of Micronesia, a non-Bank member country, is represented. Please feel free to participate in our dialogue.

* Vice-President (Projects), Asian Development Bank.

Apart, also, from the potential application of sail in the significant coastal and interisland shipping traffic of all the countries represented here, and potential development of sail-assisted design by countries which have a strong tradition in the construction and repair of regional vessels of many kinds, it should also be noted that wind energy can be readily used in the inland waterways of this region. Bangladesh and Burma, in particular, have known this for many centuries and further development in this field, if carefully applied, may lead to the more efficient use of wind power without disturbing the delicate fabric of historically established, social and entrepreneurial organizations.

Let me also welcome the representatives of the international and regional bodies in attendance here today, such as the United Nations Economic Commission for Asia and the Pacific, the Food and Agriculture Organization, the South Pacific Bureau for Economic Cooperation and the Overseas Development Administration. We appreciate your recognition of the international value of the subjects to be discussed at this Conference. We are also deeply aware of the keen interest expressed in our results by a number of internationally involved development bodies, including the United Nations Economic Commission for Latin America and the Caribbean, the World Bank, the Inter-American Development Bank, the OPEC Fund and Kuwait Fund.

We are heartened by the large number of observers present. Your special skills and experience are of direct relevance to this Conference, and we request your participation in the dialogue. In this regard, we take special note that representatives of international ship classification societies and the International Maritime Organization are present. We recognize that the principles of maritime safety and proper construction are of particular importance in this exploratory field of sail-motor propulsion. We request you, gentlemen of these organizations, to offer this Conference your advice wherever you consider it appropriate. We also hope that the media representatives present will assist us in applying their broad regional and deep local knowledge of shipping to the conclusions developed at this Conference.

Convinced of the wide-reaching importance of fuel saving in reducing transport costs and the potential offered by the sail-motor concept, our objectives during the next four days of presentations, discussions and workshop sessions will be:

a) to learn from the work of researchers in sail-motor and related studies the potential level of such fuel savings, the various means of sail assistance currently available, and those which may be applied to vessels of various sizes and types;

b) to recognize the necessary inputs, institutional constraints and levels of technology which apply in specific experiments, both within and outside our Asia-Pacific region; and

c) perhaps the most important of all, to engage in a dialogue, a dialogue which will result in a more detailed appreciation of the operational and institutional environments in which the various shipping fleets of this region operate and, therefore, to judge the most appropriate avenues, levels of technology and shipping policy development which may be applied to the sail-motor concept in our own situations.

In developing these Conference objectives the Bank has drawn upon its earlier investigations. Beginning in 1980 and following shortly after the launching of Japan's first successful sail-assisted vessel, the *Shin Aitoku Maru*, it was recognized by Vice-President Bambawale, who unfortunately left the Bank a few weeks ago, that the application of sail in this region has enormous potential. Under his guidance and continued support, our earlier investigations led us to the view that, while drawing on the lessons of applied high level technology and new fuel efficient sail-assisted ship designs developed in Japan, and more recently in other countries, such as France, United Kingdom and United States, there is also an important potential role, especially in the short term, of applying the sail retrofit principle. That is, the low-cost fitting of sail to those many existing vessels, however small, which were built in an era of cheaply available fuel and which for many reasons are likely to remain in operation throughout our region for several more years to come. It is very apparent to us that interisland and coastal transport relies heavily on such vessels, the owners of which are generally not well placed to take immediate advantage of the potential for new, fuel-efficient building on a large scale. Indeed, we also recognize that there is considerable value in gaining experience with retrofitted vessels, towards a much better understanding of the direction in which new sail-assisted vessels particularly smaller ones, should develop, in terms of their detailed designs, their efficient management and the level of sail technology to be applied.

With this principle in mind, a practical retrofit experiment was embarked upon in Fiji, using a typical interisland cargo passenger vessel of about 300 deadweight tons. This experiment, I hasten to add, was only made possible by the kind assistance of the Government of Fiji, which, in recognizing the value of such an experiment to Fiji and the region as a whole, provided, free of charge to the Bank, a suitable experimental vessel and her crew. The close cooperation of the Government of Fiji, the skill and motivation provided by the Bank's consultants and the crew, ensured the

experiment's success, in spite of the untimely loss of the vessel while at anchor during one of the most devastating hurricanes to hit Fiji in recent years. However, convinced of the value of the experiment, the Government of Fiji has provided a second vessel with which to continue the experiment.

Ladies and gentlemen, neither the Bank's experiment nor those outlined in the papers to be presented at this Conference represent a final answer to the regional potential for use of sail by merchant shipping and some papers will indicate the need for a careful approach in various respects. Following this Conference the Bank will publish a set of revised papers, together with the results of your questions and answers, workshop sessions and your Conference conclusions. These Conference Proceedings will aim to assist you and your Governments in considering appropriate future applications of sail. The quality of these Proceedings, as a useful tool in this endeavor, therefore depends very greatly on your own individual participation. Consequently, I extend the sincere wishes of the Bank that you will be successful in achieving a stimulating Conference and in preparing the way for a very useful final document.

CONFERENCE CONCLUSIONS

Conference Conclusions

John F. Brooks

BACKGROUND TO THE CONFERENCE AND SUMMARY OF THE PAPERS

In 1980, shortly after Japan launched its first successful sail-assisted vessel, the *Shin Aitoku Maru,* the Asian Development Bank (ADB) recognized the enormous potential of the sail-motor propulsion concept[1] for marine fuel savings in the Asia-Pacific region. As also noted by Mr. Schulz in his keynote address, subsequent research carried out by the Bank showed that, while sail-assisted ship designs developed in Japan were very fuel efficient, there was a potential role for the low-cost sail retrofit concept.

The Benefits of Sail Demonstrated

The experiment referred to by Mr. Schulz,[2] involving the 300-ton interisland cargo passenger vessel *Na Mata-I-Sau,* indicated that very favorable economic internal rates of return and a short, approximately 1.5 year payback period on the financial investment of around $40,000 may be expected. It was demonstrated that at least one-quarter of the vessel's fuel costs could be saved by proper use of sails in conjunction with the engines, without loss of operating speed or without impeding cargo operations. In fresh to strong winds, full operating speed was also realized with the engines completely shut down. In average wind conditions of around 15 knots, the ship's speed without engines was within 20 per cent of her usual operating speed. The latter mode was found to be particularly applicable when port arrival time was not critical or when speed reduction could be used to coincide port arrival time with normal early morning cargo work or exchange of passengers.

1 Under the sail-motor propulsion concept, a ship's required operational speed is maintained under reduced engine power by the auxiliary use of sail.

2 TA No. 508-FIJ: Experimental Study on Sail-Motor Propulsion.

The rot resistant roller-furling sails were also found to be easily controlled by two or three seamen. Within five minutes all sails could be completely furled clear of the cargo hatches and passenger areas. The mainsail boom, which doubled as a cargo derrick of 1.5 tons capacity, could also be made immediately available to load and unload the ship's cargo. In addition, the vessel became considerably more comfortable for passengers when under sail and the vessel's safety was improved by the presence of a reliable, auxiliary means of propulsion.

Convinced of the value of the experiment, and following the loss of *Na Mata-I-Sau* while at anchor in a hurricane, the Government of Fiji provided a second vessel for the Bank's use. The *Cagidonu* is a 350-ton cargo-passenger ship and was fitted with a sail rig similar to that of the *Na Mata-I-Sau*. Experimental sail trials and crew training were concluded under ADB consultant supervision, with the same encouraging results. The immediate task now remains for the trained crew to continue operating the vessel under sail while gathering further data on operational conditions and fuel savings. This ongoing data-gathering exercise will proceed under the Government's supervision throughout 1986 in order to achieve well documented results.

Bank-Sponsored Conference

The readily achieved results under the experiment in Fiji by no means represent the complete answer to regional requirements in sail-motor development. In this regard, the ADB recognizes the need to explore and communicate the potential application of other sail-motor solutions. Consequently, the Bank opted to sponsor a Regional Conference on Sail-Motor Propulsion.

The Conference was held in Manila from 18 to 21 November 1985, and was attended by government representatives concerned with shipping administration and policy, maritime safety, maritime education, and private-sector shipping operations, from 20 developing member countries (DMCs) of the Bank. In addition, the Conference was attended by about 40 observers, several of whom represented international bodies.

The objectives of the Conference, as outlined in the keynote address by Mr. Schulz, may be summarized as follows:

- to learn the current status of research and fuel saving potential in the sail-motor field;
- to recognize the necessary inputs, constraints and levels of technology which apply in specific sail-motor experiments; and
- to consider the most appropriate technology and shipping policy development which may be applied to the sail-motor concept in our particular regional countries.

Following an introductory overview by Dr. Satchwell, wherein the basic concepts, terminology and broadly defined options and project appraisal methodology under the sail-motor concept were explained, 12 papers were presented at the Conference.

Conference Papers

The first paper, by Mr. Constans, dealt with ongoing experiments by the French Fondation Cousteau, including the results of a successful trans-Atlantic voyage by the experimental vessel *Alcyone*. *Alcyone* is propelled with the assistance of two Turbosails. The Turbosails are tubelike aluminum structures which are designed to create a strong dissymetry in the pressure field on the two sides of each Turbosail to produce a large lift coefficient and resultant high propulsive force. The minimal deck space requirement and simplicity of control give the system an exceptional aptitude for automation and application to commercial shipping. By computerized synchronization with the engines the system can run the ship at a constant speed while minimizing fuel consumption. Currently, a small tanker is being equipped with Turbosails which are expected to provide between 30 and 55 per cent fuel savings, with a 10 per cent increase in ship speed.

This glimpse at the potential application of new technology was followed by an outline by Mr. Marchaj of the basic principles and value of controlled experimental tests and research in sail development. These principles were then discussed in terms of some recently conducted wind tunnel tests on various soft sail planforms at Southampton University, which indicate that traditional sails, such as the crab claw rig developed by the Hawaiian islanders many generations ago, are highly efficient. The clear message was that soft sails will always provide a relatively low cost but efficient option for sail-motor development.

Dr. Hamada next introduced the results of his pioneering work in developing the technically sophisticated Japanese sail-assisted vessels during the past seven years. He particularly emphasized the importance of overall efficiency in ship design and the need to integrate engine design and control with sail usage. Dr. Hamada noted that the experience in Japan in recent years confirms that modern sail applications have a valuable role in energy savings.

Mr. Palmer, using the example of intraisland transport needs in Tonga,

set out a useful methodology for evaluating the need and potential for sail in a specific locality. Mr. Corten of the UN-ESCAP, Bangkok, jointly emphasized with Mr. Palmer the importance of gaining a thorough comprehension of the socioeconomic background into which transport improvements are proposed. This vital factor was again made clear in an evening film made and presented especially for the Conference by Mr. Baharadin Abidin of Hassanudin University on the traditional interisland sailing vessel sector of Indonesia.

The joint Government of Fiji/ADB sail retrofit study was presented by the consultant team leader, Mr. MacAlister. The encouraging and ongoing results of this study have been described earlier in the background section of the Conference conclusions. This was followed by an introduction to the joint Government of Indonesia/Federal Republic of Germany INDOSAIL project by the Conference Chairman, Mr. Suleman Wiriadidjaja, and Mr. Schenzle. From this interesting presentation it was learned that the project emphasizes the strengthening of Indonesia's vast and continued experience in sail by developing modern and powerful sailing vessels, able to efficiently compete with interisland motor ships in every respect, except speed. The background to this important project was expanded by Mr. Harahap in his introduction to the Workshop sessions, in which he reinforced the project's focus of taking every modern technological advantage to provide vessels where safety, minimum delay in cargo operations and ease of maintenance are major conditions for compatibility with the selected sailing rig.

Admiral Khan and Dr. Chowdhury then brought the Conference focus to bear on inland waterway applications of sail and opened our eyes to the historical and deeply embedded social context of sail in Bangladesh, where 60 per cent of employment in the transport industry, which serves the country's 68,000 villages, is in the nonmechanized country boat sector. The enormous potential value of improving the efficiency of sail and the vital and possibly increasing future importance of the nonmechanized country boat sector in this least developed country was convincingly described. That such improvements in sail efficiency are technically feasible, and at modest cost, was fully discussed in relation to the successful National Oceanographic and Maritime Institute's experimental project in Bangladesh.

Turning from inland waterways, another specific shipping-related sector was explored by Mr. MacAlister in regard to the application of sail in the fishing industry. The important lesson to be learned was that experiments in the use of sail, while being highly beneficial in reducing the operating costs of fishermen, especially in artisanal fisheries, always need to take full account of training needs and the importance of demonstrating, in practical terms, the full value of sail assistance.

Ship Management Aspects

Professor King commended the Japanese approach to the use of sail, by reminding delegates that a ship must be considered as an integrated system as far as energy savings are concerned. He also cautioned that all operating costs are not wrapped up in fuel, and that a broad spectrum of tactical advantage-seeking decisions existed among shipping competitors. He further noted that crew costs currently dominate in the cost-cutting efforts of ocean-going shipping groups. However, Professor King also supported the view that a valuable role exists for sail, particularly for small vessels, if individual shipowners perceive a need for it and provided the installation costs of sail in its various possible forms are found to be financially justifiable.

Professor Brookfield, in drawing on a deep knowledge of the Pacific and other island regions, examined historically based problems of interisland transport. He cited that patterns of ship ownership and control, both commercial and political, are worthy of careful study, together with a recognition that sail application should go hand in hand with other development needs for innovative ship designs, particularly those which can avoid the need for costly provision of port infrastructure on small islands. Professor Brookfield drew particular attention to the dominant need to carry the unitized cargo concept forward as far as possible into the trading system. He suggested that this area would offer the greatest challenge both for sail retrofitting and for new ship designs.

The value of sail in refined shipping management was developed more specifically by two innovative papers by Dr. Mays and Dr. Satchwell which examined the use of models. Dr. Satchwell focused on the application of linear windship theory to optimize rig design, and to answer questions on procurement and optimal routing under sail. Dr. Mays described the various components and applications of weather routing, but gave special emphasis to the concept of power routing as it may be beneficially employed on shorter routes under sail, such as interisland services, where often the only element of routing control is the balancing of power between the sail rig and the power plant, to seek an equilibrium speed while factoring in the economics of sail assistance. In particular, he discussed the value of a simple on board decision-making tool, for examining the trade-off between the opportunity costs of later arrival times in port versus added fuel costs of a speedier voyage.

SUMMARY OF WORKSHOP SESSIONS

Introduction and Objectives

The Workshop sessions, on the final day of the Conference, as chaired by Mr. Harahap,[1] were planned to:

(i) Summarize comment on the various papers presented from the viewpoints of the delegates with their widely ranging professional experience and qualifications;

(ii) Ensure that conclusions emerging from the Conference took into account such comment from the delegates, in addition to the more formal question and answer sessions which followed the presentation of each paper; and, in particular,

(iii) Focus specific technical knowledge gained from the Conference onto the regional development potential of the sail-motor concept.

The Workshop sessions proved most useful in drawing together, in an exploratory fashion, the lessons of the practical studies and experiments presented at the Conference. Delegates took the opportunity at these sessions to consider the potential role of sail-motor applications in terms of their own shipping management and development needs. The main findings of the Workshop groups are summarized separately, but each group firmly concluded that communication of development in technology, sensitive awareness of the operational context of a particular shipping enterprise and practical demonstrations and experiments are the key factors to consider in sail-motor development.

Scope of Workshop Sessions

The Conference delegates had earlier indicated their individual preferences regarding the three discussion groups offered, namely:

(i) Inland waterways;

(ii) Coastal and interisland; and

(iii) Interregional shipping.

1 See also Workshop introductory paper by Marah S.M. Harahap, "Compatibility of New Sail Techniques with Present Interisland Shipping Practices in the Asia/Pacific Region, an Indonesian Case".

Following the Workshop introductory paper, delegates broke up into the discussion groups. Each group was led by an official country participant as Group Coordinator, who was assisted by a Resource Coordinator from among the Resource Persons. The main conclusions reached by each discussion group, as herein recorded, were subsequently reported in a plenary session.

The question and answer sessions conducted after each paper presentation and as reported elsewhere in these Proceedings, provided additional and very substantial information and discussion of a more detailed nature.

Workshop Conclusions

Inland Waterways Group

Based on individual experiences and their countries' characteristics, the following key problems were identified by the group members regarding use of sail in inland waterways:

(i) Shallow waters;

(ii) Restricted navigation; and

(iii) Low wind resources compared to open sea routes.

The appropriate level of technical potential for pure sail or sail-motor was considered to vary greatly from country to country within the region, and careful assessment of each situation was needed. It was concluded that improved communication of technical knowledge will greatly assist in evaluating this potential. The group, therefore, recommended that:

(i) Regional countries refer to the Bank for assistance in realization of a project's potential, either for funds or information;

(ii) Further assistance in funding demonstration projects be considered by the Bank and other funding agencies. These projects should also include provisions for extension work and training; and

(iii) The crab claw rig should be further examined in research projects.

Coastal and Interisland Group

The principal conclusions reached by the Coastal and Interisland Group were as follows:

(i) Computer modelling should be fully utilized in assessing the performance and optimal use of sail-motor technology;

(ii) Coordinated dissemination of information on sail-motor propulsion, obtained through experiments, is important to the selection and adoption of appropriate technology in each situation;

(iii) Local skills, materials and customs must be fully taken into account, so that solutions will be within the grasp of the persons involved and can be maintained at the proper level; and

(iv) Individual shipowners must be fully aware of the costs and benefits, and how the playoff between the two factors will affect the financial outcome, before significant and useful investment in sail-motor technology will occur.

Capt. Maharaj of Fiji was asked to outline the advantages and disadvantages of using sail assistance, in light of his experience with the Bank-assisted project involving a soft sail system on a typical interisland cargo-passenger vessel. These were summarized by Capt. Maharaj as follows:

1. *Advantages:*

   (i) Significant reduction in fuel consumption;

   (ii) Better steering and comfort in rough weather; and

   (iii) Closer awareness of variations in engine performance.

2. *Disadvantages:*

   (i) Reduced visibility from the bridge;[1] including the creation of small blind sectors on the radar which may be caused by masts; and

   (ii) More care is required in ship maneuvering.

Interregional Group

The Interregional Group perceived the primary objective of shipping as the means to provide efficient, and not necessarily speedy transportation

1 On the specially designed INDOSAIL vessel this problem is being addressed by defining an upper limit for the wheelhouse position and a lower limit for the sail.

of goods. The group enumerated the following overall priorities that should be considered in relation to sail assistance to achieve this primary objective:

(i) The total system should ensure a financial return on expenditures;

(ii) While shipowners in some nations may emphasize fuel savings, others may need to emphasize reduction in other operational costs such as crew costs, time spent in port and insurance premiums. However, none of these aspects were considered to necessarily be incompatible with sail development;

(iii) A sail-assisted system should attempt to minimize the use of deck space and reduction in a ship's stability;

(iv) Adoption of sail assistance will entail additional costs due to structural changes in the hull and automation of engine controls;

(v) Except for the cylindrical devices applications of a rigid sail system will be generally limited to tankers, bulk carriers and roll on-roll off vessels;

(vi) Sail assistance introduces additional processes, such as trimming and handling of sails and monitoring of engine power. These factors introduce important management considerations at the shipboard level which must be fully resolved by automated or substantially manual activities, as appropriate, if a system is to be successful, whatever its potential for fuel savings;

(vii) Shipowners may be reluctant to adopt a new technology and may perceive that they have insufficient capacity to absorb the risk of failure. Thus, the provision of information in a suitable form must be a priority consideration; and

(viii) At present, there are no clear international agreements on safety matters which specifically relate to sail-assisted vessels.

MAIN CONCLUSIONS OF THE CONFERENCE PROCEEDINGS

Sail-motor technology has undergone rapid development in the last few years, with encouraging results being achieved from ongoing practical studies. As a general conclusion, approximately 25 per cent of a ship's fuel may be saved by the application of sail assistance without compromising required operational schedules.

The degree of sophistication of a sail-motor system must be carefully assessed according to specific local requirements. Of particular importance are economic, commercial, technical, regulatory and training aspects.

Concerns that the use of sails might interfere with cargo handling requirements as well as ship, passenger and crew safety, are generally unfounded, in light of the new technology being developed. Indeed, ship comfort and safety can be enhanced by the addition of sail. However, careful attention must be given to detailed operational requirements and overall financial benefits in any successful or worthwhile sail-motor propulsion venture. In this regard, sail development must go hand in hand with innovative developments in cargo handling efficiency and reduction of port time.

Practical studies have shown that soft sail systems are relatively low in cost. Moreover, maintenance and control is easy where roller-furling is employed and synthetic and noncorrosive sail and rig materials are used. Also, costs need not be exorbitant for mechanical rigid sail systems and such applications are highly suited to computerized integration with engine and navigational control.

Shipowners are traditionally conservative with regard to innovative technology. In view of the wide range and priority of considerations which clearly differ in every situation, the potential for developing new, sail assisted ship designs may be most appropriately approached through practical, relatively low-cost sail retrofitting experiments, especially for smaller vessels.

Appropriate sail-motor development may also be assisted by the introduction of international conventions. In this regard, maritime nations have the International Maritime Organization as their well established and universally recognized secretariat at their disposal, especially in relation to safety and environmental matters.

Finally, the Bank intends to further assist its DMCs in appropriate applications of sail-motor development by means of project loans, technical assistance and subloans from development finance institutions. It is hoped that, by publishing the Conference Proceedings, our primary objective to assist those concerned with shipping and energy conservation in the Bank's DMCs will be progressively achieved.

CONFERENCE PAPERS

An Overview of Wind-Assisted Propulsion for Commercial Shipping

Christopher J. Satchwell*

INTRODUCTION

The aim of this paper is to provide a background and context needed to appreciate the papers that will follow. Our subject at the Conference is wind-assisted propulsion for commercial ships, with particular emphasis on how it affects countries of the Asian Development Bank's region. The main sea areas are the Indian Ocean, with its alternating monsoon winds and the Pacific Ocean, which has a pattern of trade winds that have had a major influence on both Polynesian and European voyages of discovery. Much of the region's history can be linked to the trading opportunities presented by these winds and the Conference will re-examine such opportunities against a background of modern technology and economic conditions.

A wind propulsion device may be used in conjunction with an engine to:

(i) save fuel while maintaining a reasonable service speed;

(ii) improve the motion of a vessel;

(iii) lessen noise and vibration; and

(iv) provide an alternative means of propulsion in the event of an engine failure.

The degree to which these benefits are present depends on the rig, weather, route, engine/propeller design and hull form. The relevance of these benefits to the region will be outlined broadly and delegates may

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perceive detailed opportunities for their country's or their own shipping operations.

Within the region there are numerous islands (at least 30,000 in the Pacific), as well as many isolated coastal communities. Such communities are often served by small, slow, old ships, which were designed in an age of cheap oil for a service speed that these ships may never again reach. The economic viability of such communities has been threatened by successive oil price increases, through a cruel process of increasing transport costs for both imports and exports, making costs rise and incomes fall. A policy of ship replacement or sail retrofitting would save oil and make such communities less vulnerable to oil price fluctuations. Some additional local employment might also be created to operate and maintain these sail assistance devices, which would then be financed out of part of the fuel savings. Thus, some of the money that might otherwise go to a foreign oil company is diverted, through employment, back into the local economy.

Much of the region's economy is dependent on sea transport over vast distances. In view of an economic dependence on sea transport, the region has a strategic interest in making shipping costs as low as possible. Much of the region is also short of oil and has an interest in reducing its vulnerability to oil price fluctuations. Wind propulsion can help with both shipping costs and oil price vulnerability, and should be viewed with interest by both the developed and developing parts of the region.

Source data for this paper come from previous conferences such as Comsail '80, Florida '80 and Windtech '85, as well as internal Southampton University studies. Subject matter consists of impressions distilled from the source data and the paper has been designed to provide an introduction to wind-assisted propulsion for commercial shipping.

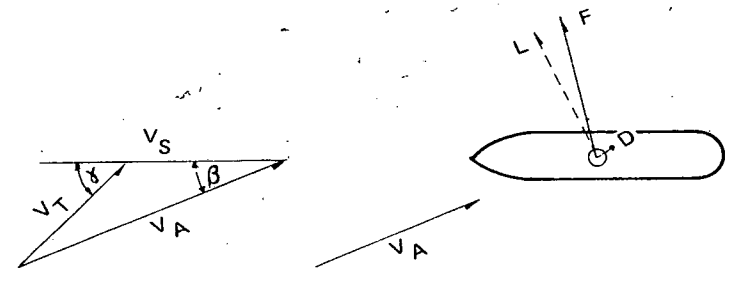
BACKGROUND TO WIND PROPULSION

Most experience with wind-assisted propulsion has been gained through the use of sail rigs. This has generated its own vocabulary, much of which is applicable to other wind propulsion devices and outlined here in association with suitable diagrams. Sailing vessels are operated according to the apparent wind speed (V_A) and apparent wind angle (β). A diagram showing the relationship between true and apparent conditions is shown in Figure 1.

Sail settings are varied to produce aerodynamic forces appropriate to the point of sailing. Typical sail settings for various points relative to the wind are shown in Figure 2. A sailing vessel cannot point directly into the wind, but can move in a windward direction by tacking on a zig-zag course.

Figure 1

Apparent and True Wind Conditions



(a) WIND VELOCITY TRIANGLE

(b) RIG AIRLOAD (F), RESOLVED INTO COMPONENTS OF LIFT (L) AND DRAG (D)

KEY

V_S – SHIP SPEED

V_T – TRUE WIND SPEED

V_A – APPARENT WIND SPEED

γ – TRUE WIND ANGLE

β – APPARENT WIND ANGLE

The extra distance incurred by tacking may be avoided by lowering the sails and motoring upwind.

When tacking, a sail causes both a substantial side force and heeling moment on a hull (see Figure 3). To balance a sail side force, the hull is steered through the water at a small leeway angle (λ), so as to hydrodynamically generate an equal, but opposite side force to that of the sail. The heeling moment causes a heel angle which may become large in strong winds. If this happens, it is usual to reef the sails. The destabilizing effect of a sail may limit the size of the rig a vessel can carry. The hydrodynamic side force generates additional resistance which reduces the effective propulsion from the sail. This additional resistance is known as induced resistance (Ri).

A DESCRIPTION OF WIND PROPULSION DEVICES

Sail Rigs

Sail rigs have been designed in many different forms, according to need. Occidental designs for specialist upwind or reaching/downwind use have been either fore and aft or square rigged respectively. Traditional fore and aft rigs made use of triangular sails, which are now being superceded by long thin quadrilateral sails. The wishbone ketch rig of the *Na Mata-I-Sau,* the Fijian vessel retrofitted under the Bank's experiment and rigs developed for the INDOSAIL project, typify the trend away from triangular sails towards tall, thin quadrilateral sails. Sketches of these rigs are shown in Figure 4. Traditional oriental rigs evolved to adapt local materials to the sail performance requirements of a vessel. Many of these rigs perform very well at sea and are still frequently the most cost-effective sail rigs in the environments where they evolved. There are arguments for not changing these sail rigs, especially where they give good sailing performance and are cheap to build. However, if additional sail performance can be obtained, without adverse implications for vessel stability and financial costs, arguments for changing sail rigs become strong. Later in the Conference results will be presented to help with questions of rig selection. In recent years, a more scientific approach has been adopted to questions of customer requirements and rig performance. Results of this approach are typified by a Japanese automated rig for ship propulsion and a rig developed as part of the INDOSAIL project. Both these rigs will be referred to later in the Conference.

Sail rigs also provide aerodynamic damping to reduce the rolling and pitching motion of a vessel. This benefit is important and in some cases

Figure 2

Points of Sailing

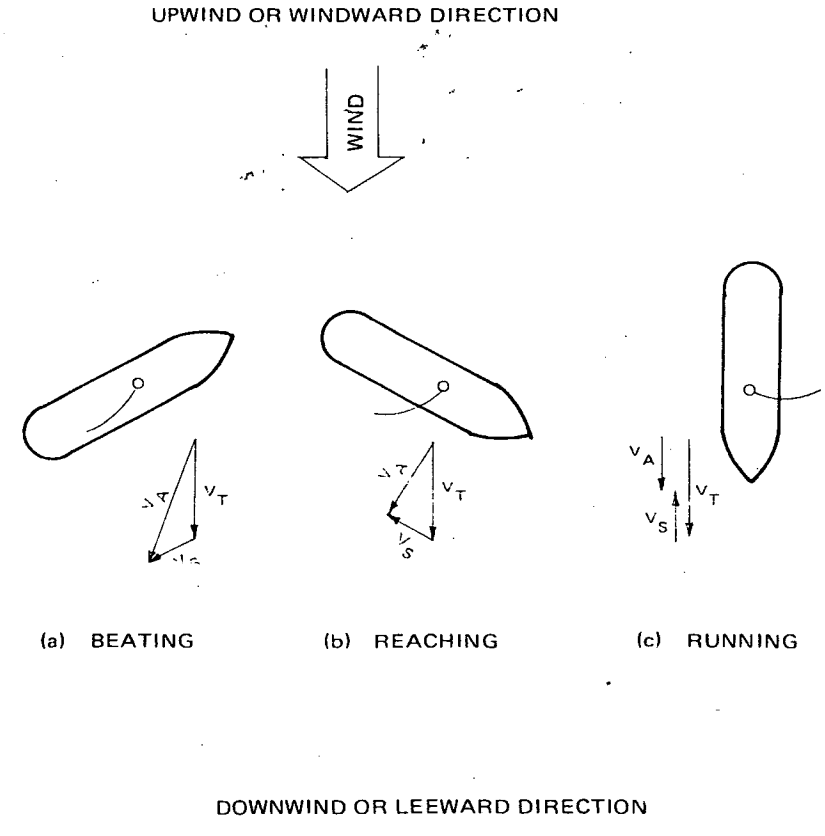


Figure 3

Sail-Hull Interaction

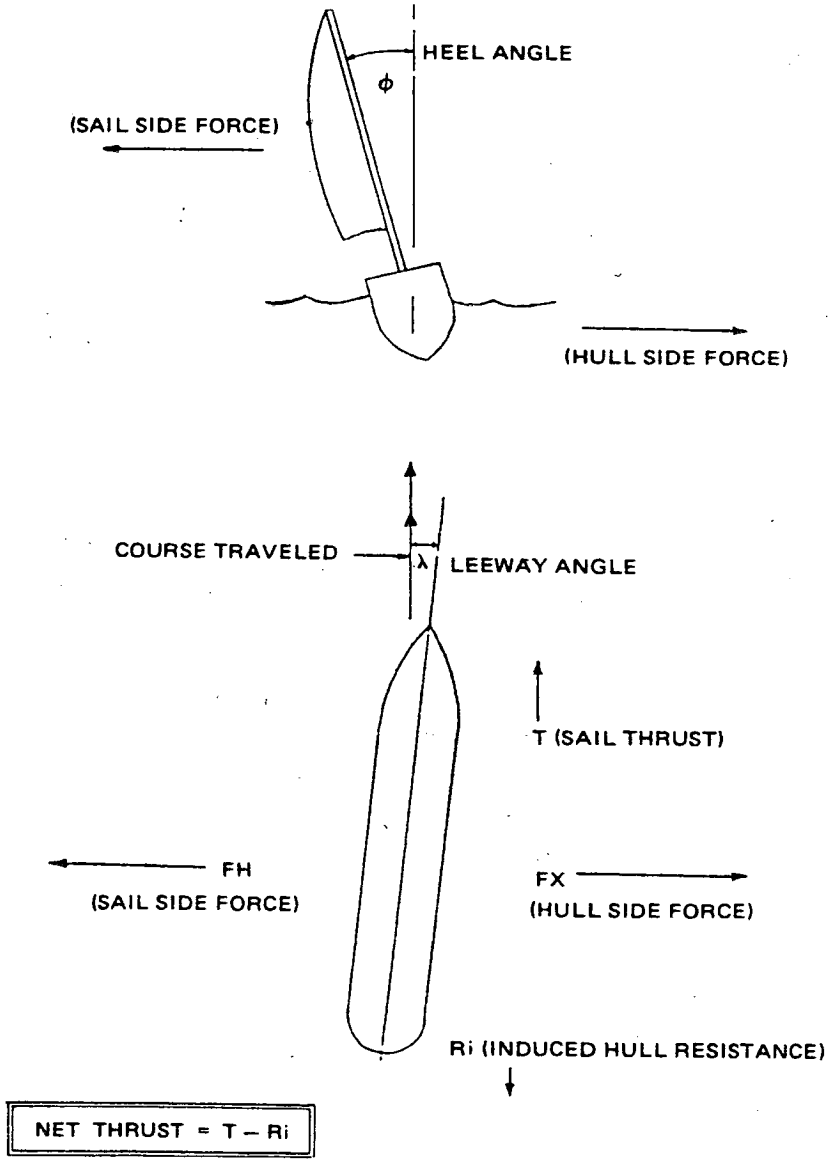
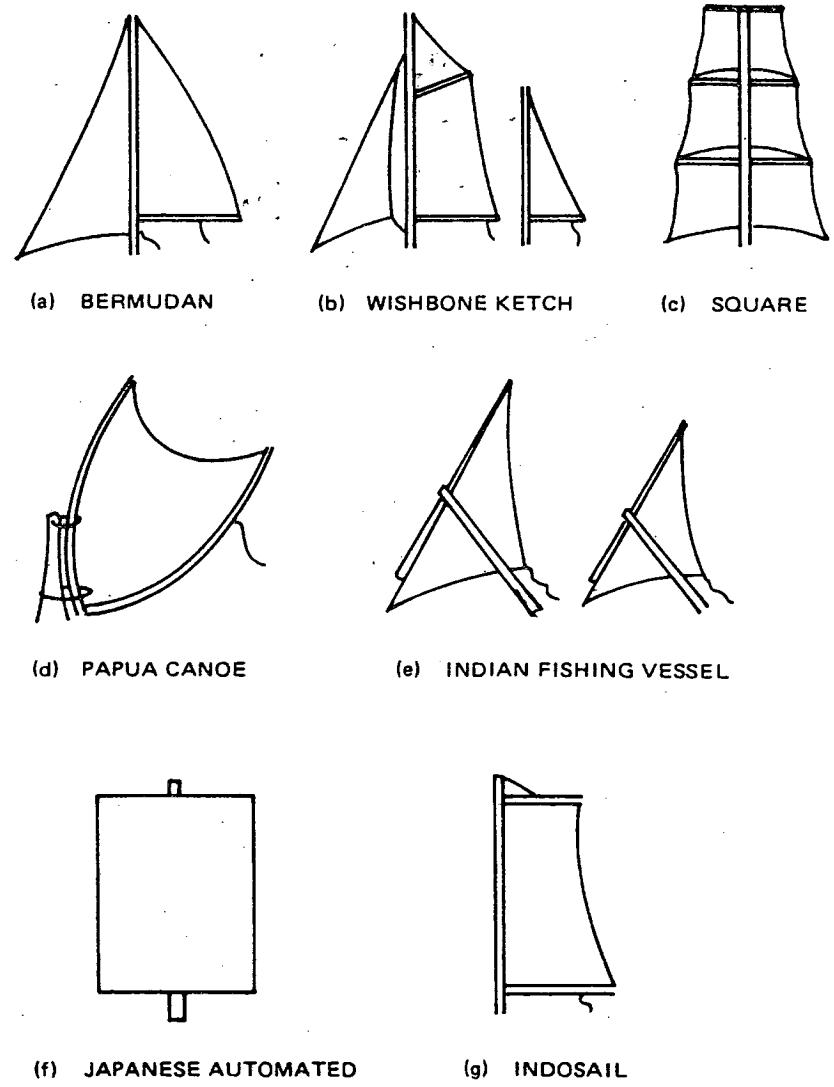


Figure 4

Various Sail Rigs



may justifiably be the sole reason for fitting a sail rig. Performance of sail rigs depends on many factors including planform[1], numbers of sails and height. Upwind sailing requires a high lift/drag ratio, which can be obtained with a tall rig. Unfortunately, tall rigs generate large heeling moments and problems with roll stability. This conflict between upwind performance and stability is one of many that occur in sail rig design. On reaching, or downwind courses, lower lift/drag ratios are acceptable and so low or medium height rigs may be used.

Rigid Airfoil Rigs

Rigid airfoil rigs (see Figure 5) have been developed for ship propulsion, in situations where a vessel has adequate stability and the wind arrives from a predominant direction which is forward of the beam. Examples are the Gallant rig, the Walker wingsail and the author's hybrid flapped multiplane rig. Relative to sail, these devices can produce much more propulsive force from a compact region of the superstructure. They are free-standing structures and avoid the need for permanent rigging connecting them to the ship. This means that crane access and cargo handling tends to be easier than for sail rigs. Like sail, they may be used as the sole means of propulsion, which implies that if an engine fails, they can still drive the vessel. However, they provide very little propulsive force on downwind points. On most other courses they provide aerodynamic damping of ship oscillations, but not to the same extent as sail. Rigid airfoils are most applicable where deck space is at a premium and cargo handling ability important, or where very good upwind performance is needed. The use of 'engineering' material is required in the construction of rigid airfoils.

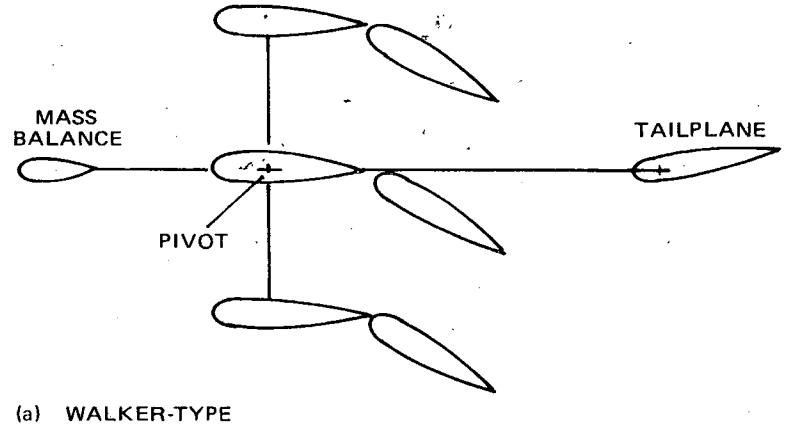
Mechanical High Lift Airfoils

With mechanical high lift airfoils, some external source of energy is used to control the airflow around a form of airfoil, to make that airfoil more effective. An example is a rotating cylinder, such as that designed by Flettner for use on the vessels *Bukan* and *Barbara* some half a century ago. More recently, the idea has been redeveloped by both Gifford Technology Ltd. and the Windship Development Corporation, with working prototypes built. Flettner rotors show promise as low-cost retrofit devices for slower vessels, with winds arriving from a predominant direction close to the beam. They also take up significantly less deck space than other rigs.

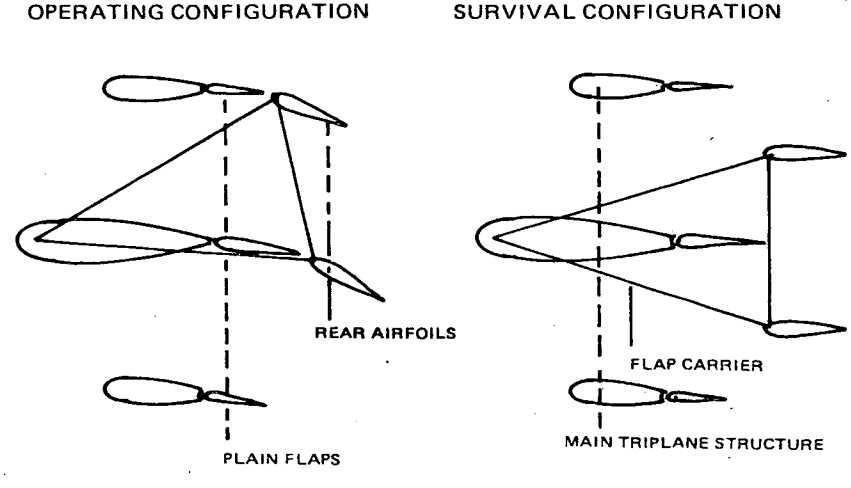
1 Planform refers to the shape of the individual sails and the shape of the overall rig.

Figure 5

Samples of Rigid Airfoil Rigs
(Sectional Views)



(a) WALKER-TYPE



(b) HYBRID FLAPPED MULTIPLANE (HFM)

Other approaches to the design of mechanical high lift airfoils involve the use of suction (Cousteau rig), or air blown into the airstream from tangential slots. The suction/blowing approach implies a need to simultaneously control both incidence and the volume of sucked/blown air, which involves a more complex control system than that of the Flettner rotor. Some sketches of mechanical high lift airfoils are shown in Figure 6.

Some general points about these devices also need to be made. They all depend on external power and there may be situations where fault causing the loss of a main engine also causes the loss of the power supply to the mechanical high lift airfoil. If this happens, the mechanical high lift will not provide emergency propulsion. Mechanical high lift airfoils also tend to have a base drag higher than that of rigid airfoils, but about the same as that of a sail rig. This has some implications for performance, which will be discussed later.

Kites

The use of kites for ship propulsive purposes is believed to date back at least two hundred years, when Samoan islanders used them to tow canoes. Basic principles are shown in Figure 7, where it can be seen that kites provide propulsion on a wide range of upwind and downwind courses.

Kites can provide wind propulsion without a heeling moment. They can be stowed away in port, are cheap to make and easily retrofitted to almost any vessel. However, they have not been adopted so far because they have problems with launch, flight control and retrieval. On small boats, the use of kites can also cause a vessel to take off into the air and land upside down. Use of kites is particularly appropriate where surface winds are light, as they are in many parts of the region. Typically, windspeed at an altitude of 250 meters is 50 per cent greater than that at ten meters, leading to more than a threefold increase in wind power available. This may explain why kites were used by Samoan islanders and suggest their future use in the region should be taken very seriously.

Wind Turbines

Wind turbine rigs have unique qualities, making them difficult to compare with other rigs. When air moves relative to the sea, it is possible to use a wind turbine to extract kinetic energy and then use that energy to drive a water propeller. Figure 8 shows a schematic drawing of a wind turbine rig. This rig allows propulsion in any direction, including dead to

Figure 6

Mechanical Highlift Airfoils

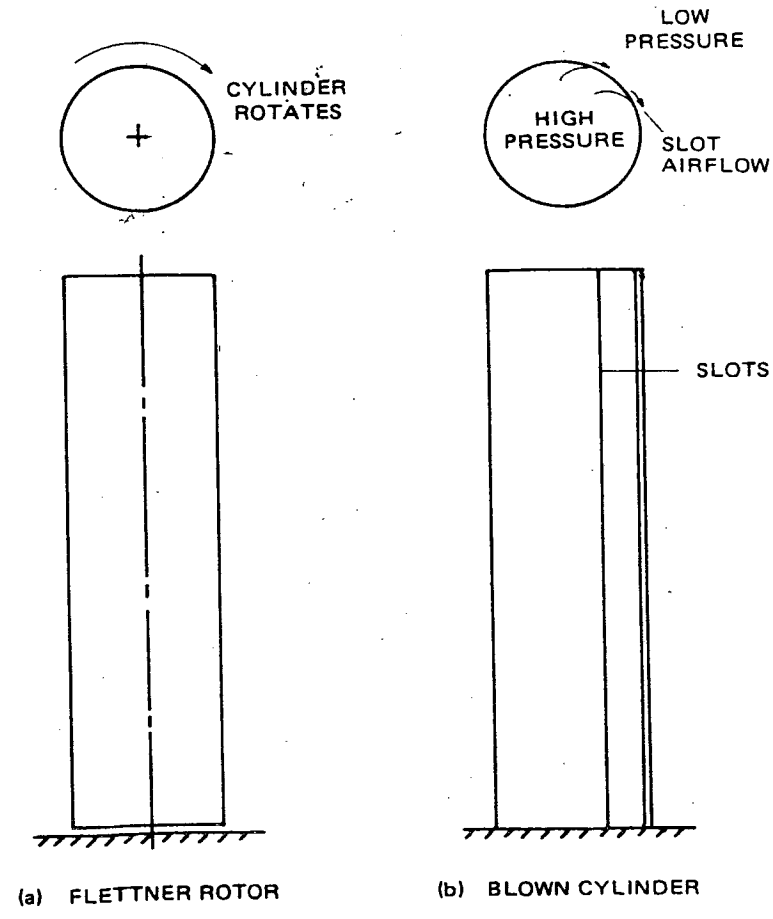


Figure 7

Kite Propulsion

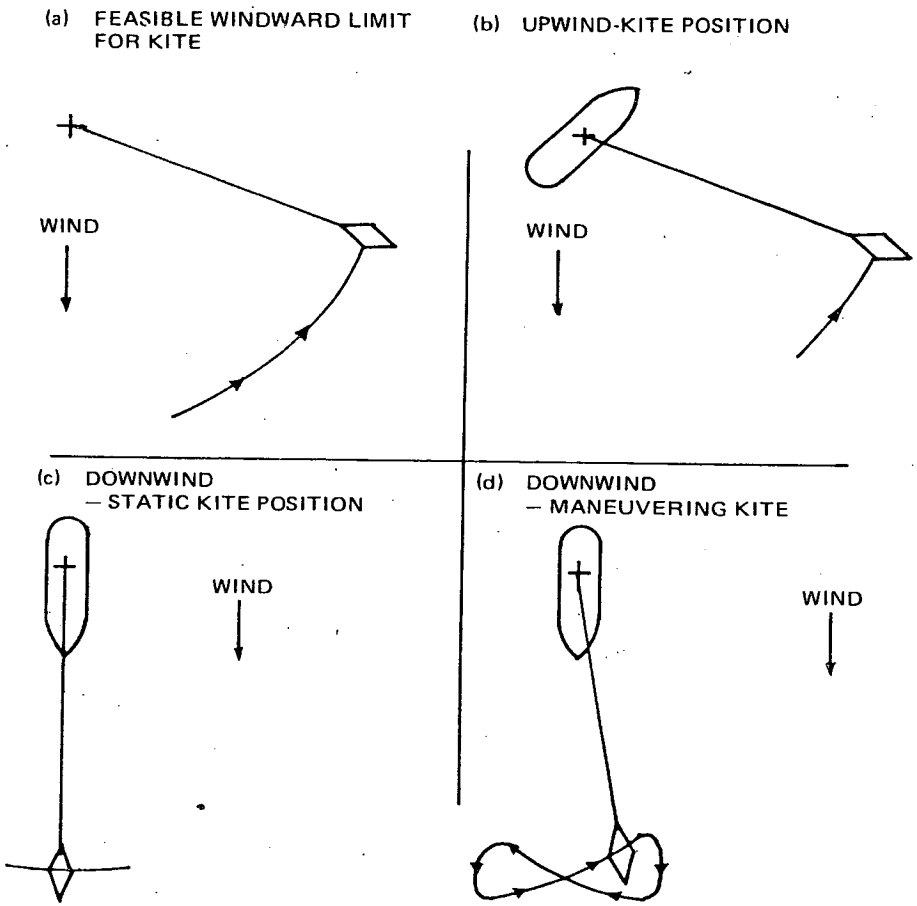
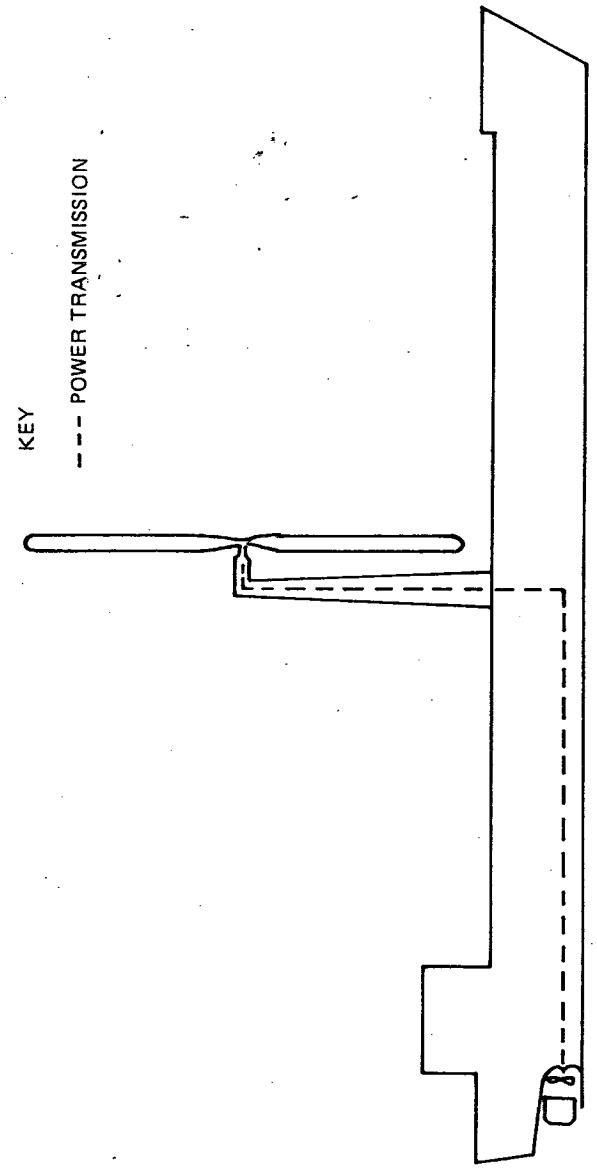


Figure 8

Schematic Drawing of a Wind Turbine Rig



windward. On reaching courses, a wind turbine may be decoupled from a water propeller and used in an autogyro mode, to provide propulsion in a similar manner to that of a sail. At anchor, the wind turbine may be used to provide power for either shipboard or external use. These rigs work best when the ship speed (V_S) is only a small fraction of the true wind speed (V_T) which suggests towing applications. Other possible uses include barges on inland waterways and aerogenerator platforms.

PERFORMANCE OF WIND PROPULSION DEVICES

The justification for fitting any wind propulsion device will probably come from its propulsive performance. From Figure 1, it can be seen that apparent wind conditions depend on ship speed (V_S), true wind speed (V_T) and true wind angle (γ). The dependence of apparent wind conditions on these variables enables the performance of wind propulsion devices to be approximately described in terms of the two variables γ and V_S/V_T. Absolute information regarding the relative performance of these devices is not available, but results from Windtech '85 and other studies have allowed a series of recommendations to be prepared for the applicability of different rigs, when performance is the only consideration. Table 1 gives broad guidance for the application of these devices in different parts of the $\gamma \sim V_S/V_T$ region. The omission of a device from a square in Table 1 may mean either that the device does not work at all or, simply that other devices work better.

From the operator's viewpoint, representative values of γ need to be found from the route network and historical weather information. Values of V_T can also be found from historical weather data. (Mean values of V_T are typically 13 knots.) The value of V_S offers some scope for flexibility. In normal shipping operations, V_S is a compromise between an argument to go fast so as to improve the productivity of the vessel, and an alternative argument to go slow so as to burn less fuel.

These conflicting views result in typical compromises involving ship speeds of 18 knots for a container vessel, 14 knots for a general cargo vessel and 12 knots for a bulk carrier. General trends are:

(i) Expensive cargo results in a high ship speed;

(ii) Expensive labor results in a high ship speed;

(iii) Expensive fuel results in a low ship speed; and

(iv) Use of an old vessel results in a low ship speed.

Table 1

Key

A	– rigid airfoil	K	– kite
M	– mechanical high lift device	γ	– true wind angle
S	– soft sail	V_S	– ship speed
W	– wind turbine	V_T	– true wind speed

γ / V_S/V_T ↓	0°	30°	60°	90°	120°	150°	180°
.5	W	W, S M, K	W, S M, K	W, S M, K	W, S M, K	W, S M, K	W, S M, K
1.0	–	A, M S	A, M S, K	A, M S, K	A, M S, K	A, M S, K	A, M S, K
1.5	–	A	A, S M	A, M S, K	A, M S, K	A, M S, K	K
2.0	–	A	A	A	A	A	
2.5	–	–	A	A	A		

There are no strict rules for an ideal ship speed, but for nearly every shipping operation there will be some optimal speed which should be sought and used. The use of a wind propulsion device makes the choice of ship speed even more complicated, although it is still possible to develop the necessary analytical models to provide the information to make a selection.

In conclusion, when V_S, V_T and δ are known, Table 1 can be consulted and an appropriate wind-assist device should be indicated. This indication is solely on the grounds of performance and leaves open the question of other factors which may influence a rig procurement decision.

OTHER FACTORS INVOLVED WITH WIND PROPULSION DEVICES

The use of a wind propulsion device will have implications for other aspects of ship operations and one of the aims of this paper is to outline some of those implications.

Cargo Handling

Traditional sail rigs require shrouds, stays and other standing rigging which will impede crane access to holds. The use of well-designed onboard cranes in conjunction with modified rigging (see the INDOSAIL rig) can overcome this problem. In the case of many other wind propulsion devices, intrusion into deck and air space is sufficiently small to permit the use of dockside cranes.

Manning

With most traditional sail rigs, manning levels are high. Some newer sail rigs have been designed for both simplicity and low manning by virtue of the sail planform and method of reefing (for example, furling Genoa staysail rigs). Other rigs are also designed for low manning through the use of automatic reefing mechanisms on more aerodynamically efficient planforms. With rigid airfoils, mechanical high lift airfoils, and wind turbines, extra manning requirements should be minimal. In the case of kites, current designs will require additional manning, but it should eventually be possible to reduce such additional manning levels to those of a modern sail rig.

Reliability and Maintenance

For wind propulsion devices made from 'engineering' materials, for example, rigid airfoils, mechanical high lift devices and wind turbines, reliability should be high and maintenance requirements low. Sails and kites are made from woven materials which are vulnerable to mechanical damage, as fibers rub against each other. Woven materials may also be vulnerable to damage from ultra-violet degradation and bacterial attack. Lower reliability and higher maintenance must be expected with wind-assist devices involving the use of fabrics.

Ship Motion Improvement

The foregoing discussion under Performance of Wind Propulsion Devices was concerned with the propulsive effect of sails and other devices. Another important effect, the ability to improve the motion of a vessel, needs to be considered in selecting any such device. Experience with sail retrofit on powered vessels shows that rolling is reduced, thereby improving the living conditions on board. This important benefit makes sailing vessels popular with passengers and crew, can minimize cargo damage and may beneficially affect ship resistance.

Ship motion improvements depend on the wind propulsion device employed. With kites and Flettner rotors, little ship motion improvement can be expected. With rigid and suction airfoils, more ship motion improvement should be present, but sails produce the biggest improvements. This picture of ship motion improvement may become obscured by the overall height of the various devices. Aerodynamic damping depends strongly on rig height and it is sometimes possible to improve damping by making a rig taller.

Air Draft

The height of a wind propulsion device may prevent a vessel from traveling under a bridge and interfere with its ability to earn revenue. One sail rig has been designed with a lowering mechanism to reduce air draft and enable passage beneath bridges. Similar mechanisms could easily be designed for rigid airfoils and mechanical high lift airfoils. Kites present no problems in respect of air draft as they may be retrieved before going under a bridge.

Other Factors

The preceding points are frequently raised in discussion of wind propulsion devices. There will always be individual factors such as the

availability of maintenance skills, availability of foreign exchange and a dependence on spare parts that may have to come many thousands of miles. These factors can materially affect the choice of a wind propulsion device. For example, where foreign exchange is short and foreign communications poor, an appropriate choice might be a simple sail rig that can be maintained locally.

THE CHOICE OF A WIND PROPULSION DEVICE

The choice of a wind propulsion device is not always obvious, nor is a method for making that choice. One possible method involving three distinct stages is presented below.

Assessment of Operational Implications

Possible wind propulsion devices can be selected from Table 1 and assessed for suitability with the proposed operation of the vessel. The aim of this exercise is to eliminate devices which are operationally unsuitable. For example, a wind turbine might be dangerous to passengers, a sail rig might take up too much deck space, a kite might place excessive demands on the crew and a mechanical high lift airfoil might not offer emergency propulsion. Once devices that are operationally feasible are established, probable benefits can be examined.

Assessment of Probable Benefits

The primary benefit of a wind propulsion device is fuel saving. Potential fuel savings can be calculated by methods as shown in Comsail, 1980 and Satchwell and Mays, 1983, using the assumption that any energy provided by the wind does not have to be provided by the engine. Typical engine, power/fuel consumption curves are then used to convert the wind energy provided into a fuel saving and financial benefit.

This type of method has some weaknesses in that:

(i) Engine fuel usage is normally higher than manufacturers' figures available for these methods;

(ii) Engine usage with wind-assistance needs to be carefully thought out in order to realize fuel saving opportunities. Arbitrary engine usage may result in arbitrary realization of wind-assisted fuel savings; and

(iii) Additional benefits from weather routing are overlooked. Some limited operational experience has been successfully correlated with predictions, and the method can tentatively be claimed to provide a reasonable prediction of the propulsive fuel savings produced by these devices.

In addition, there may be substantial but unquantifiable fuel savings arising from ship motion improvements. There may also be increases in both passenger and cargo revenue if ship motion improvements are present.

Thus, wind propulsion fuel savings may be divided into the quantifiable and the unquantifiable, both of which will usually be positive. Other non-financial benefits such as extra employment and reduced engine noise should also be considered. The importance of these benefits will vary depending on the operator and the nature of his business.

Assessment of the Balance of Advantage

Potential wind propulsion devices can be compared using the quantifiable fuel savings and some investment appraisal criteria, such as the financial internal rate of return (FIRR). The FIRR is a measure of return on investment, based on expected profits over the lifetime of a project, averaged on a yearly basis. With a new vessel, it may be best to calculate the impact of a wind propulsion device on the FIRR of investment in both ship and rig. For other vessels, the ship element of the investment needs careful appraisal. Frequently, results are presented as an FIRR on rig investment only.

Unquantifiable fuel savings and other benefits, such as improved ship motion, foreign exchange savings and provision of an emergency means of propulsion can then be considered and applied to results from an investment appraisal. Subsequently, a final rig selection can be made.

CONCLUSIONS

This introductory paper has prepared the ground for later papers. Principles of sailing have been outlined and different categories and performance propulsion devices described. Performance of wind propulsion devices is shown to be dependent on ship speed/true windspeed (V_S/V_T) and true wind angle (γ).

Additional benefits, such as ship motion improvement, are mentioned as well as implications for other aspects of ship operation.

A broad outline is given for a method to select an appropriate wind propulsion device and a table is also included to assist in selection. A rig

selection method is included here to provide an important context which may be required to judge the information to be presented later in the Conference.

Later Conference papers will give much more information about specific wind propulsion devices, operating techniques and methods for calculating the energy supplied by the wind. Such information is essential for the successful introduction and operation of wind-assisted ships within the Indian and Pacific Ocean areas.

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QUESTIONS AND ANSWERS

Q: You showed us a slide of the Nibanga hybrid flapped multiplane (Figure 5). Can you give us an idea, in terms of numbers, of the relative efficiency of these devices? (Mr. R. G. MacAlister)

A: The hybrid flapped multiplane proposal for the Nibanga project was formulated to produce fuel saving identical to the sail rig. The projected area of the hybrid flapped multiplane was only 1/5 of the projected area of the sail rig. If you want a broad number for the size of a modern device as compared to the size of a sail rig, you could take the area of the sail rig and divide it by 5, and you will get a fairly representative figure for fuel savings that can be expected with a modern device.

Q: You have given us an idea of the relative sizes of various rig configuration. Can you give an indication of the relative costs because that is another consideration in the choice of device? (Mr. C. Palmer)

A: These techniques are, in most cases, experiments and costs for custom-built equipment are bound to be high and vary enormously between different systems. A retrofit such as that carried out for the Fiji-ADB experiment cost about US$50,000.

Q. In your presentation you referred to tacking as a tortuous process. Tacking is that process of beating to windward which often on conventional sailboats can be quite slow, particularly under light wind conditions. One of the major themes of this Conference is the symbiosis or the combination of sail and motor. Under these conditions, the ratio of boat speed to true wind speed is often significantly greater than it would be under sail alone. And you just mentioned the smaller vessels that have such a ratio of about 0.5 and for larger vessels the ratio might be about 1.0. Under those conditions would not tacking be a far more efficient process and far less tortuous than your paper implies? (Dr. J. Mays)

A: That particular part of the paper was really intended to give the nontechnical people some background on sailing techniques. I would agree with you on this point. Tacking on the sail-motor is much more efficient than tacking under pure sail. And I would like to go into the reasons for that.

From Figure 3, induced resistance is a consequence of having to generate side force. Indeed resistance under sail-motor is far less than it is on the pure sail and this enables very efficient tacking. Also, you will find that the apparent wind speed over the sail is much greater when the motor is used, as opposed to when the sail is used as the sole means of propulsion. So, you get far more sail force and less resistance whenever you are tacking under the sail-motor situation. However, I am not sure that ship's crews would do this unless tacks are fairly long.

Q: In response to your comments on the benefits to be derived from use of sail, will these benefits outweigh the additional costs incurred in crewing and in building the wind-assistance devices? (Mr. A. B. Thakur)

A: Fuel savings will be obtained with the use of sail. In my paper later during the Conference, I will describe these benefits. Capt. Maharaj is going to provide some figures on the fuel savings and other benefits for *Na Mata-I-Sau* in Fiji. With regard to your question about the cost of having additional crew, the number of crew depends on the type of sail rig and that the rig may be selected according to particular needs.

Q: Has any work been done in universities on the feasibility of retrofitting sail to existing tonnage? (Capt. G. Veres)

A: Some research has been done. At the Windtech Symposium, it was concluded that propulsion systems will work more efficiently with the fitting of wind-assist devices to existing vessels.

Q: What is the lift coefficient of the hybrid flapped multiplane system? (Mr. J. Constans)

A: There is a coefficient of 4.7 with the second model, with a potential to achieve about 6.0. However, this does not relate to fuel saving potential.

Q: Has there been any work done in developing Chinese junks or Arab dhows? (Admiral M. H. Khan)

A: There is some work in the United Kingdom on modified Chinese junk rigs. I would like to refer you to Mr. Marchaj's paper in which will be discussed the relative efficiencies of these rigs.

Q: If hull resistance can be reduced then less power would be needed to propel a vessel. Would the use of hydrofoils achieve this? If so, can this be adapted to a sail-motor vessel to maximize the effect of the sail and cut down the motor power? (Mr. T. T. Jovellanos)

A: The use of a hydrofoil to reduce hull resistance is effective at very high speeds but not at the speeds currently used by merchant ships. Sail-powered hydrofoils have proven successful, and there is no reason why sail-motor hydrofoils could not also be made to work. There has been one proposal for a high-speed, sail-assisted container vessel using hydrofoils, to obtain a predicted service speed of 100 knots. This proposal has not attracted an order but was put forward by a competent naval architect on the basis of his previous successful sail-hydrofoil design.

Q: A vessel that is tacking travels a longer distance and consequently consumes more fuel. Is there any formula or data available to help a vessel's master in deciding whether it is more economical to tack or to forego sail assistance and proceed directly to his destination using mechanical power? (Mr. S. M. dela Merced)

A: It would be possible to develop this type of criteria for calm water conditions in steady wind flow. Such ideal conditions are never met in practice and, as the calculations would be to establish the difference between two inaccurately computed quantities, the result would be unsatisfactory. With research into operational results, however, useful guidelines could be produced for particular vessels.

Alcyone, Daughter of the Wind — The Ship of the Future*

Jacques Constans**

INTRODUCTION: GENESIS OF THE TURBOSAIL SYSTEM[1]

When Captain Cousteau decided to study the building of a new oceanographic research vessel, he established two specific goals from the beginning. Not only should *Calypso II* be an ecological ship, that is, not releasing any pollution, but it should also be a model for energy conservation through the maximum use of a renewable energy source abundant at sea, namely, the wind.

A research team was formed under the scientific leadership of Professor Lucien Malavard, a member of the French Academy of Sciences. An in-depth bibliographical study was launched at the beginning of 1980. A complete review was made of all existing wind-powered systems utilized or potentially useful as supplementary propulsion for a ship. The respective advantages of these systems were compared: classical sails of the Marconi type and square sails, soft or rigid; computer controlled rigs of the Dynaship type; wind turbines with horizontal or vertical axes; rotors based on the Magnus effect; and airfoils, directly derived from aeronautics, with various high lift devices working through a variation of the geometry of the profile and simultaneous or nonsimultaneous control of the boundary layer through suction or blowing.

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* In collaboration with B. Charrier, J.Y. Cousteau and L. Malavard.

** Vice-President for Science, Technology and International Affairs, Fondation Cousteau/The Cousteau Society, France. Mr. Constans is an engineer in fluid mechanics and has been closely involved with the development of sail assistance systems for the experimental vessels *Moulin A Vent, Alcyone* and *Commandant Henry*.

1 TURBOSAIL is a trademark of Fondation Cousteau, registered in France, with other registrations pending.

These systems could be classified into two main categories: those without energy consumption (various classical sails, wind turbines or simple airfoils) and those relying on energy consumption (rotors, aspirated and/or blown airfoils). Although the Magnus rotor system was initially considered promising because of the large possible propulsion assistance for a given wind, a detailed study of the rotor system soon revealed to us major drawbacks from the aerodynamics and safety points of view (high speed of rotation and difficulty of course changes) and from the mechanical point of view (vibration and reaction to roll and pitch). The rotor system was also uneconomical due to the high energy consumption needed to spin the rotor.

Thus, the research team abandoned the rotor system and had to innovate. What were its objectives? Before everything, a simple system was required: nonrotating but orientable to allow for course changes of the ship. Next, the ability to produce a high propulsive force was very important, even at the cost of a small energy consumption. The team selected an aerodynamic approach, but with a combination of features not previously used in concert.

From those basic requirements, two main problems needed to be solved: the first related to the external aerodynamics of the system; and second, to its internal aerodynamics.

The need to have a very high propulsive force made us consider classical airfoils with high lift devices. Unfortunately, the need for the ship to change course during navigation eliminated at once the use of slotted flaps. These can give a maximum coefficient of lift (C_{Lmax}) of the order of three but are unusable because these are asymmetrical and provide lift in only one direction. On the other hand, ordinary airfoils may be rendered symmetrical, but lead only to a C_{Lmax} of approximately 2.5, a value too low to be desirable.

Contrary to conventional aerodynamic concepts, we decided to use an airfoil with a very thick profile. This type of airfoil has poorly known characteristics because its high drag coefficient (C_D) prevents its use in aeronautics, even though it has theoretically favorable lift characteristics. However, such airfoils have the advantage of a large volume and large moment of inertia, leading to a strong mechanical property for the structure.

In a further departure from conventional thinking, we combined special devices and high lift techniques with the thick profile airfoil to attain as completely as possible the theoretical flow of perfect fluid. This was done by controlling the boundary layer, to suppress, or at least delay, flow separation, which brings with it a significant increase in the drag and a severe decrease in the propulsive force. As mentioned, the control of the boundary layer can be achieved through blowing or suction.

Although experiments on conventional (thin) airfoils show an advantage of the blowing technology over suction, obtaining a large lift coefficient (C_L) when using blowing can only be achieved by a large energy expenditure. Due to the high pressure necessary for an efficient blowing effect, such a principle leads to systems technically well adapted to the limited spaces available in airplane wings (which permit only small diameter piping). Also, the use of such a technique is perfectly acceptable during plane landings when the available engine or thruster power is considerable. However, for auxiliary propulsion systems on ships, such power is not available and the high energy requirement for blowing will defeat the primary goal of conservation.

Fortunately, the choice of a thick profile made that obstacle manageable by permitting the use of suction for boundary layer control. For thick profiles, the space available inside the structure allows a large suction flow rate without the inefficiency of energy wasting flow losses, permitting a homogeneous distribution of pressure giving low head losses. Such an aspiration, using a helicoid-type fan with a large diameter and moderate speed of rotation with direct exhaust of air along the axis of the profile, proved to be the best solution when we took into account the resulting low level of energy used to accomplish boundary layer control.

To accomplish the needs of ship navigation, the profile was provided with two aspiration areas, used alternatively, located toward the rear of the profile. Further, to gain the theoretical high lift of the profile, a suitable-sized flow separator had to be positioned correctly along the windward rear side of the profile.

A movable, combined flow-separator and suction control was installed at the rear of the profile to allow the closing of the aspiration area on the windward side of the structure, and to keep a good separation between the upper and lower surface air streams and to cause the profile, even without aspiration, to provide a small but useful effect, reinforcing the overall propulsion forces of the system.

To make these advantages practical, it was necessary to avoid any possible closed loop or bypass effect in the pressure field at the ends of the profile, through a proper control of tip vortices. This was solved by the installation of end plates at each end of the structure. Also solved was the problem of minimizing the induced drag of the system, which in the case of a large C_L is much higher than the friction drag. In aerodynamics, airfoil theory shows that induced drag is proportional to the square of the lift for a given shape. It is also inversely proportional to the effective aspect ratio of the airfoil. A major advantage of end plates, when correctly installed and calculated, is the increase in the aspect ratio derived from the foil geometry, through the well known mirror-image effect, thus reducing the induced drag.

The main objectives of the research team were achieved with the discovery of this combination of unconventional ideas, and only a few technical arrangements remained to be solved. The Turbosail system was ready to become operational.

Several series of tests in wind tunnels led to a very efficient shape of the profile and allowed us to determine the best position for the fan at the top of the structure, thereby allowing an easy exhaust of the sucked-in air. Also refined and proven through wind tunnel testing were the area, size and locations of the aspiration areas (used alternatively, depending on navigation needs) positioned at the back of the structure, to improve the stability of the boundary layer.

With such a system, it was possible to create a strong dissymetry in the pressure field on the two sides of the structure and to create the large lift coefficient desired, about three to four times than previously available. Through this combination of features, the Cousteau-Pechiney system was born. The difference between the aerodynamic behavior of a fixed cylinder and an orientable aspirated cylinder is shown in Figure 1. Figure 2 sets out the basic working principle of the Turbosail system, while Figure 3 gives a schematic view of the main components of the system. These main components consist of the orientable cylinder with its two vertical aspiration areas, the movable flow separator or flap and the helicoid fan.

AERODYNAMICS AND WIND PROPULSION SYSTEMS: A FEW DEFINITIONS

Propulsive Force and Maximum Lift

The action of a wind (W) on a wing inclined to an angle of incidence results in an effort (F) proportional to the exposed surface (S) and to the square of the speed (W).

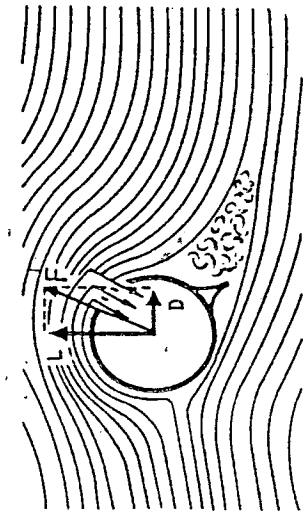
F can be then decomposed into two forces: a drag (D) in the direction of the wind and a lift (L) perpendicular to it. Two dimensionless coefficients can be then defined, the lift coefficient (C_L) and the drag coefficient (C_D). When C_L is plotted against C_D for various values of the angle of incidence α, a curve called a polar is obtained, which characterizes a given 'wing' or profile.

From such a polar, it is now easy to estimate the propulsive force (T) for various sailing courses. Figure 4 gives the expression of coefficients C_L and C_D and of the propulsive component T of effort F.

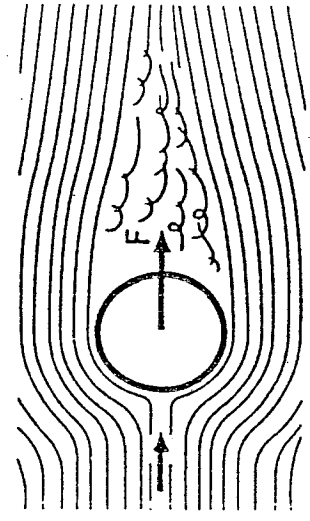
For a given wind (W) and a given angle (τ) between the ship's route and the direction of the apparent wind (W), it is the product of S by C_{Lmax}

Figure 1

Comparison of Fixed Cylinder and Orientable Aspirated Cylinder (Cousteau-Malavard)



ASPIRATED CYLINDER: Using a fan to suck air through perforated lateral vents causes deflection of the air current and high lift force. The flap at the back separates the airstreams and provides an extra push. The mechanics remain very simple.



FIXED CYLINDER: When a cylinder is placed in a moving fluid (here an airstream flowing from left to right), it offers a resistance represented by the force F, which results in a drag developing behind the cylinder. The less streamlined the cylinder, the greater the drag.

Figure 2

Basic Working Principle of the Turbosail System

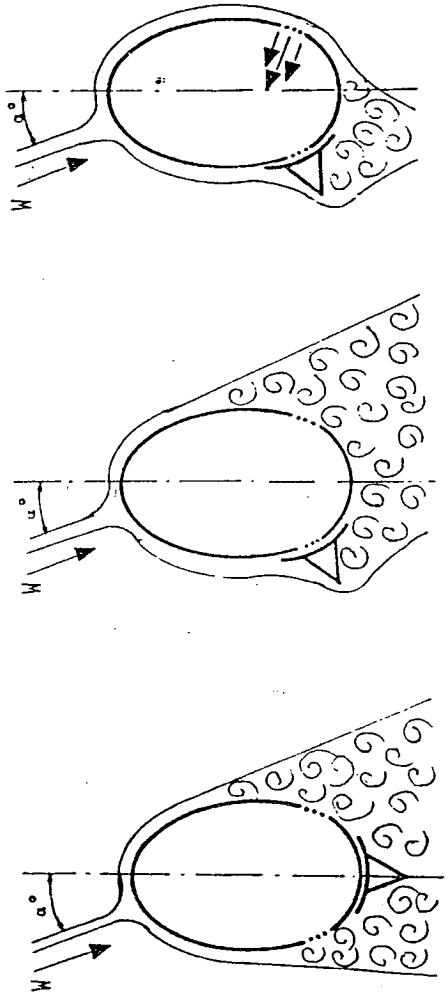


Figure 3

Schematic View of the Main Components of the Cousteau-Pechiney Turbosail System

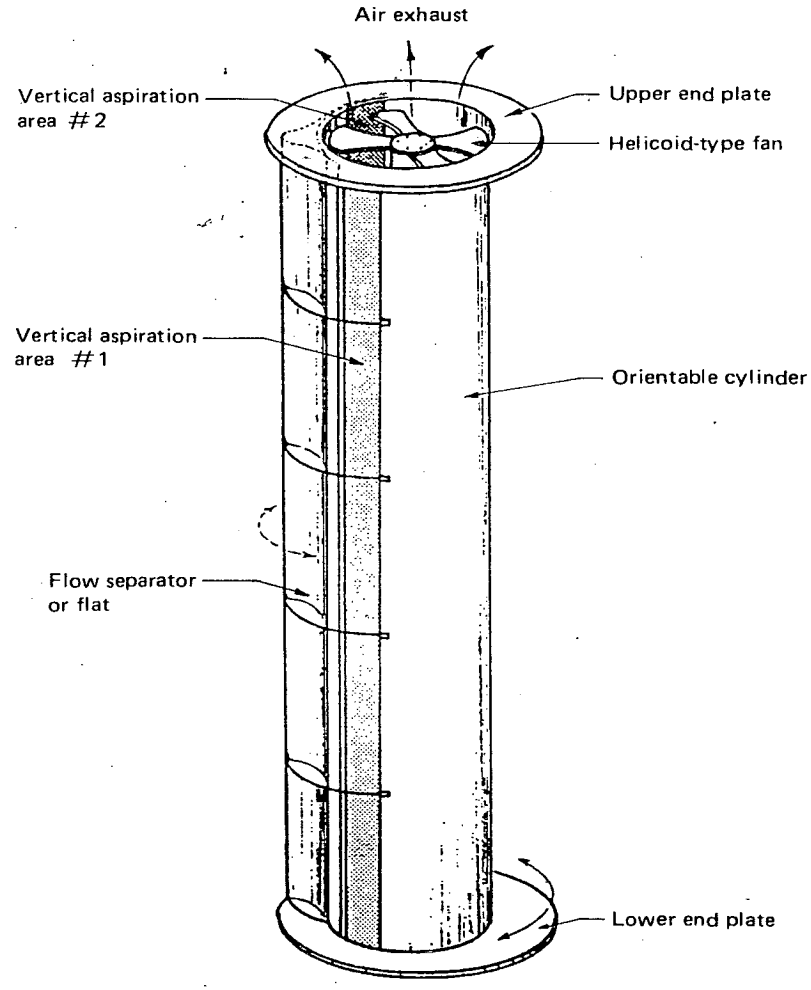


Figure 4

Lift and Drag Coefficients (Dimensionless)

$$C_L = L/(\tfrac{1}{2}\rho SW^2) \quad (1)$$

$$C_D = D/(\tfrac{1}{2}\rho SW^2) \quad (2)$$

PROPULSIVE COMPONENT T OF FORCE F

$$T = \frac{\rho}{2} W^2 S C_{Lmax} \left(\sin\tau - \frac{C_D}{C_{Lmax}} \cos\tau\right) \quad (3)$$

L = LIFT FORCE
D = DRAG FORCE
ρ = AIR VOLUMINAL FORCE
S = EXPOSED AREA
W = APPARENT WIND SPEED
C_L = LIFT COEFFICIENT
C_D = DRAG COEFFICIENT
C_{Lmax} = MAXIMUM LIFT COEFFICIENT
τ = ANGLE BETWEEN SHIP ROUTE AND DIRECTION OF APPARENT WIND

which determines the value of T . As clearly shown, also on Figure 5, the higher the C_{Lmax}, the greater the performance of a wind propulsion system, a consideration which makes the Cousteau-Pechiney system so appealing.

The Suction Energy Cost — Turbosail System Efficiency

The Cousteau-Pechiney system, like all high lift systems using energy, needs some power for the control of the boundary layer which leads to C_{Zmax} of the order of 5.5 to 6.0.

The necessary volume of air to be sucked in and the needed depression inside the profile are a function of the geometry of the profile, as well as of the position, width and permeability of the suction area.

Using flow rate coefficient (C_q), pressure coefficient (C_p), and power coefficient (C_a), it is possible to define a Turbosail system efficiency as detailed in Figure 6.

Wind tunnel and at sea experiments have shown that for commercial applications, C_a should not exceed 0.2. In such conditions, Figure 7 shows the definite advantage of the Cousteau-Pechiney solution over a number of other thick profiles, including the Flettner rotor type system.

On the basis of the exceptional results obtained during the sea experiments on a catamaran test platform named *Moulin A Vent,* it was decided in early 1984 to build a real transoceanic ship, capable of demonstrating around the world the advantages of the newly developed technology.

Alcyone, an advanced wind-assisted experimental ship, recently crossed the Atlantic ocean successfully. She is now on her way to the Cape Horn to circle the world in a two-year voyage, with major demonstration stops on the west coast of the United States, and the maritime countries of the Far East, such as Korea, Japan, China, Hong Kong, Philippines and Singapore.

ALCYONE, DAUGHTER OF THE WIND — THE SHIP OF THE FUTURE

A New Concept

Today, a new development phase has begun with *Alcyone,* an experimental ship aimed at anticipating the much larger ships of the future which will combine conventional diesel power and wind energy.

The naval architects in charge of this project, Messrs. A. Mauric and J. C. Nahon, designed *Alcyone's* shapes to combine the advantages of

Figure 5

Side Polar Diagram: Force Components for Different Angles of Attack

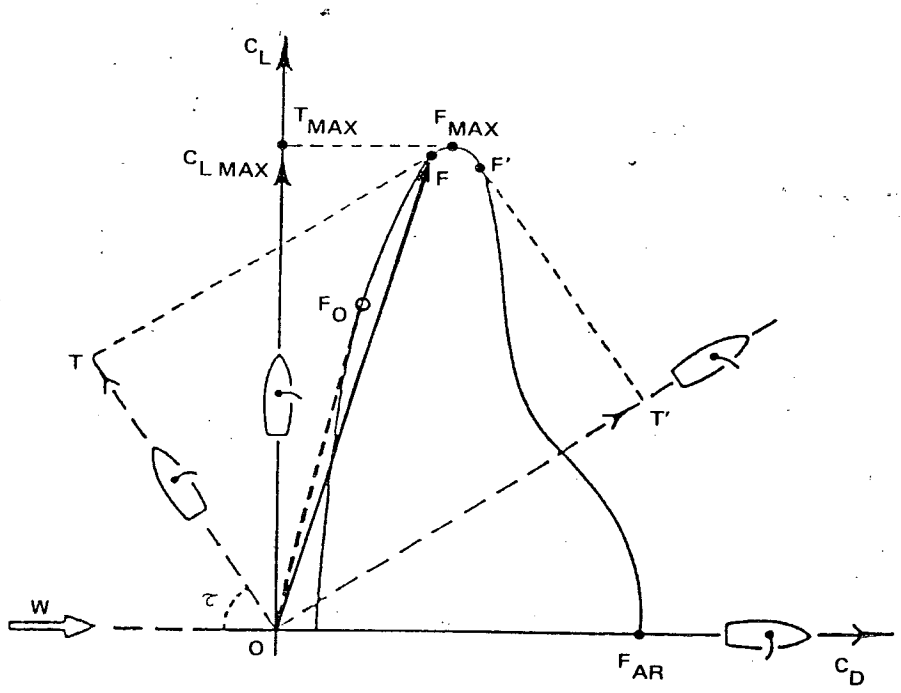


Figure 6

Suction Energy Cost & Turbosail System Efficiency

$$Cq = \frac{Q}{SW} \quad (4)$$

$$Kp = (Pc - Ps)/(\tfrac{1}{2}\rho W^2) \quad (5)$$

$$Cp = (P - Ps)/(\tfrac{1}{2}\rho W^2) \quad (6)$$

$$Ca = P_a/(\tfrac{1}{2}\ SW^3) = Cq\,.\,(Kp + 1) \quad (7)$$

$$P_T = TU \quad (8)$$

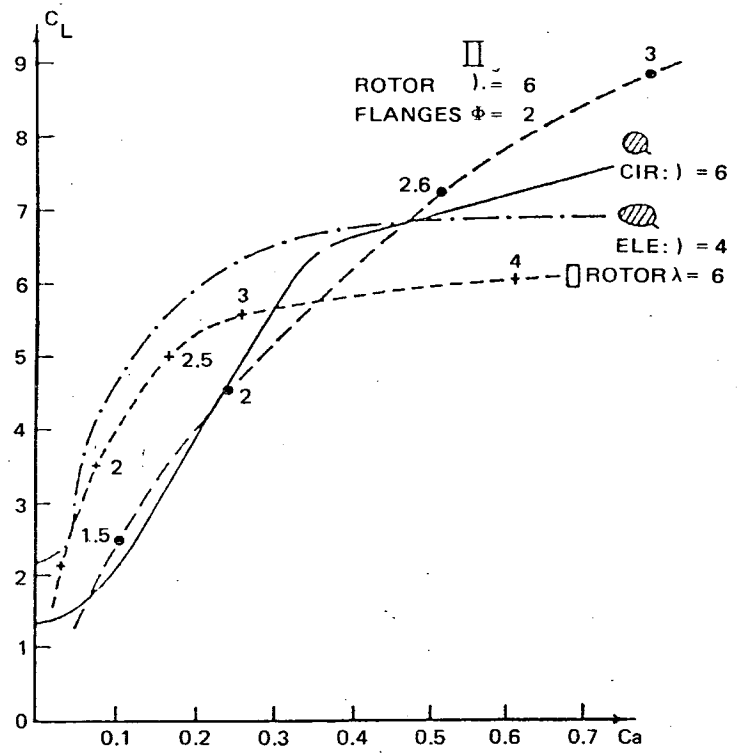
$$P_T = \frac{\rho}{2}\ W^2 U S C_{Lmax} \quad (9)$$

$$r = \frac{P_T}{P_a} = \frac{(U)}{W}\ \frac{C_{Lmax}}{C_a} \quad (10)$$

C_q = SUCTION FLOW RATE COEFFICIENT
Q = ASPIRATED AIR FLOW RATE
Kp = PRESSURE COEFFICIENTS (Kp BEING ALWAYS > Cp)
Pc = MEAN PRESSURE IN THE SUCTION CHAMBER
Ps = STATIC PRESSURE IN AIR FLOW AT SPEED
P = LOCAL PRESSURE UPSTREAM THE SUCTION AREA
Ca = SUCTION POWER COEFFICIENT
T = PROPULSIVE FORCE
U = SHIP SPEED
P_a = POWER NECESSARY FOR SUCTION
P_T = POWER RESULTING FROM PROPULSIVE FORCE T
r = TURBOSAIL SYSTEM EFFICIENCY

Figure 7

Comparison between the Necessary Power (C_a) Coefficient for the Flettner Rotor System and Two Different Aspirated Thick Profiles



monohulls and of catamarans. The result is a ship perfectly adapted to both engine and wind propulsion. The three dimensional program CIRCE-3D was used to generate a continuous numerical representation of the complex surfaces of the hull through Hewlett-Packard microcomputer systems.

The hull thus obtained has a length to width ratio as low as 3.3, which provides very good stability, a minimum heel angle under Turbosail systems, while allowing excellent performance with the engines alone or the system alone or, a combination of the two. The main characteristics of the ship are given in Table 1. The general outline of *Alcyone* is presented in Figure 8. To give *Alcyone* excellent resistance to all the agents of marine corrosion, and thus maximum longevity, the complete structure was built in aluminum alloy of the CM 5086 H111 type, made by Cegedur-Pechiney. The ship was built by the Societe Nouvelle des Ateliers et Chantiers de La Rochelle-Pallice, on the French Atlantic coast.

The Heart of Alcyone

At the heart of *Alcyone* is a control center which automatically operates the two Turbosails. Based on a multi-task computer with a graphic display, the control unit manages and drives 21 electronic, electromechanical and hydraulic actuators on the basis of information collected by 43 analog and digital sensors.

Figure 9 gives the general arrangement of the control system now in operation on *Alcyone*. With this system, it is possible to adjust and automatically optimize the main parameters of the wind propulsion system, according to conditions of navigation: adjustment of the angle of incidence of both Turbosails; position of the flaps; and rotation speed of the extraction ventilators.

Also possible is to:

(i) display on a screen all control parameters;

(ii) store the above parameters on floppy disks for eventual treatment at a later stage; and

(iii) manage the system by interactive vocal synthesis, the computer transmitting by voice suitable information to the captain or to the officer on watch.

The control unit allows the navigator to choose among four modes:

(i) adjustment of the diesel propulsion engines and of the Turbosail system can be made manually by the captain;

Main Characteristics of Alcyone

Alycone was designed by A. MAURIC and J.C. NAHON
Naval architecture and marine engineering, Marseilles – France

Built in 1984-1985 by the Societe Nouvelle des Ateliers et Chantiers de La Rochelle-Pallice – France

ALYCONE

Length overall	31.10 meters
Maximum draught	2.34 meters
Displacement (half-loaded)	76.8 tons
Number and type of engines	2 x IVECO-FIAT 8061 SMO2. 115 kW
Number and type of propellers	2 x Luke 3-folding blades
Cruising speed	10.5 knots
Crew	5

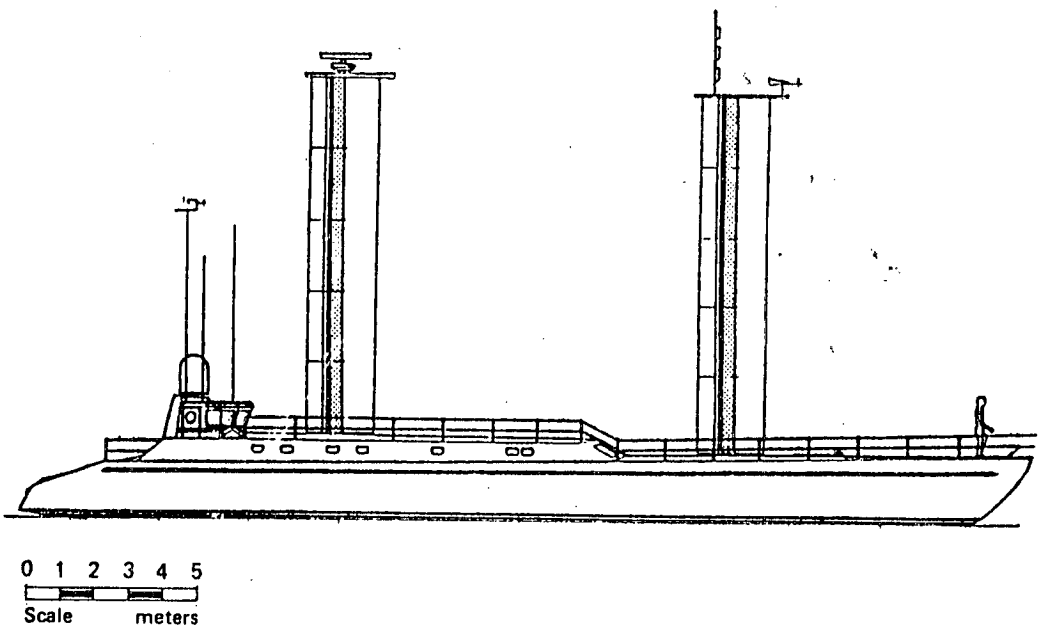
Supplementary wind propulsion by orientable aspirated cylinder: the COUSTEAU-PECHINEY Turbosail system.

Height	10.20 meters
Maximum chord	2.05 meters
Width	1.35 meters

Source : The Cousteau Society, 1985.

Table 1

General Outline of the Prototype Ship Alcyone

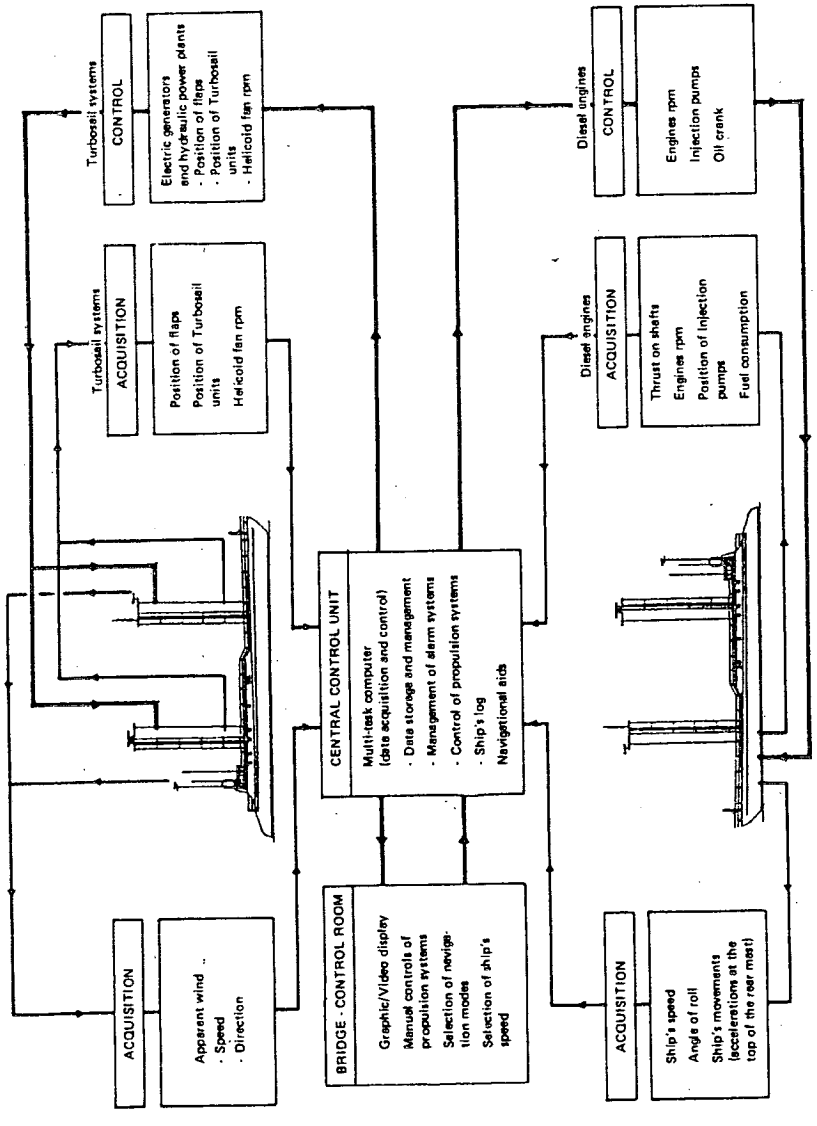


Source: The Cousteau Society, 1985

Figure 8

Figure 9

General Arrangement of Alcyone's Control System



(ii) the control can be entirely automatic and provides the strongest propulsion thrust possible for a given wind;

(iii) the diesel propulsion engines and the Turbosails can be simultaneously and automatically adjusted. In this case, the ship runs at a constant speed while minimizing the energy and fuel consumption; and

(iv) under a storm safety mode the Turbosails can be automatically adjusted in such a way that their aerodynamic drag remains at a minimum.

The layout of the bridge has been designed to allow the integration of all the management and control instruments of propulsion and navigation.

DEVELOPMENT POTENTIAL

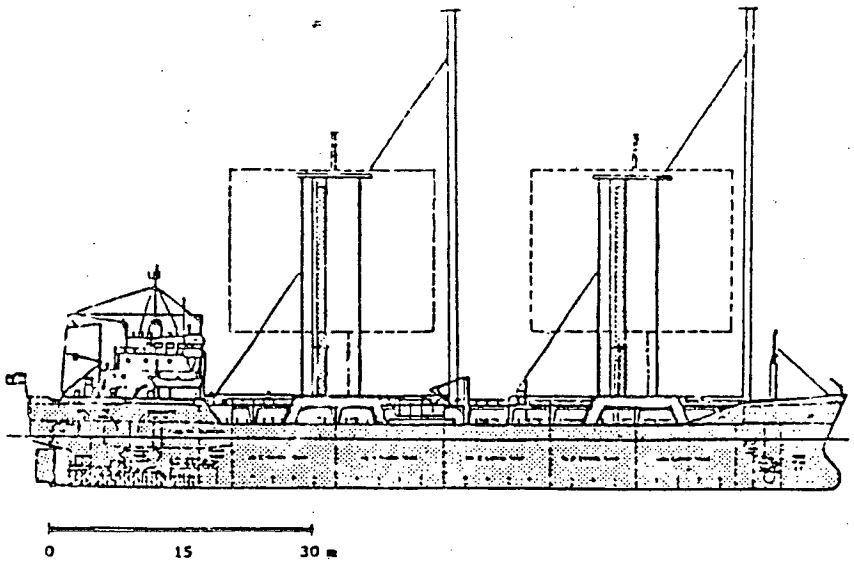
The success of the *Alcyone* not only celebrates the merging of hydrodynamics and aerodynamics but also firmly establishes the future of electronics and computer techniques in the maritime domain, outlining tomorrow's navigation methods. It is possible to develop a complete range of control units for the Turbosail system, from the simplest to the most complicated ones, according to the needs of the ships to be equipped.

The first commercial ship to be equipped with Turbosails is a chemical tanker displacing approximately 4,500 tons. The ship will be fitted with two Turbosails, each of 130 sq m. When various options for sail assistance on the vessel were considered, the compact, space saving Turbosail system was an obvious choice (see Figure 10). Over a two-year demonstration period, the ship will provide measurements of the actual fuel savings in a real commercial situation. Such a demonstration is being made possible through a grant from the Commission of the European Communities and should lead to the general use of Turbosails for supplementary propulsion on a full range of commercial or specialized ships. A simulation program developed by Fondation Cousteau/The Cousteau Society and its worldwide licensee, Cegedur-Pechiney, shows that fuel savings for the vessel may reach 30 per cent (see Figure 11).

Furthermore, various studies jointly carried out by the Fondation Cousteau/The Cousteau Society and Cegedur-Pechiney have clearly proved that Turbosails can be fitted on ships of very large tonnage. Ongoing projects planned to equip ships of 17,000, 30,000 and over 200,000 dwt should lead to new constructions in a few years to come.

Figure 10

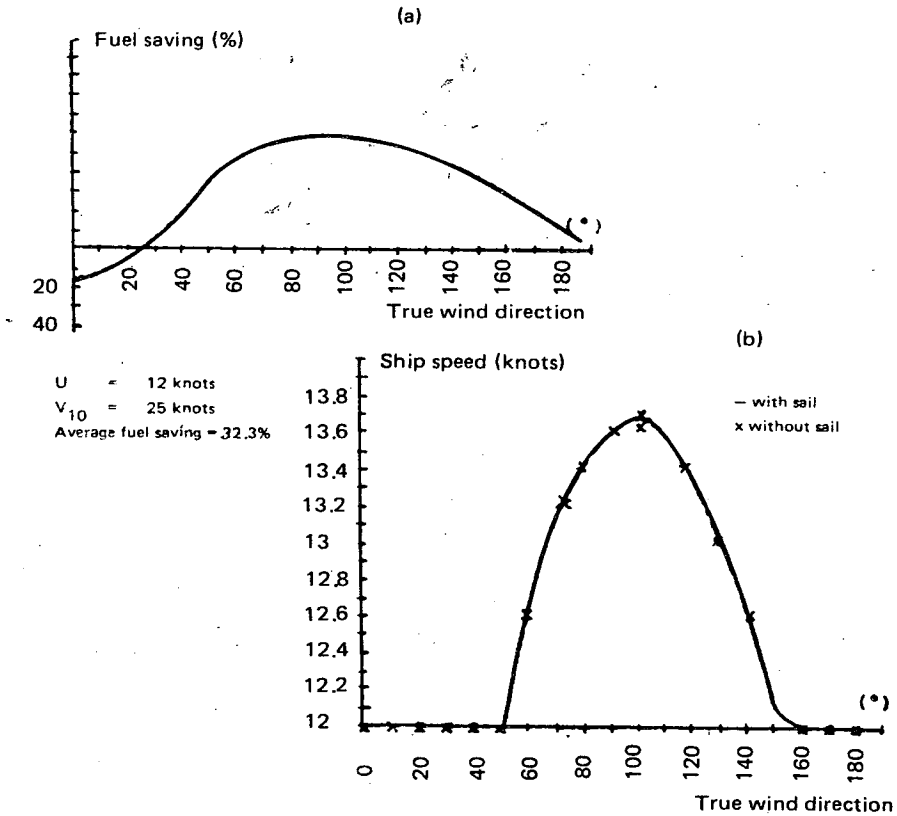
Outline of a First Demonstration Commercial Carrier, Displacing Approximately 4,500 Tons Equipped with Three Types of Sailing Gear



PROPOSED WIND PROPULSION SYSTEMS	$C_{L\,max}$	TOTAL PROPOSED EXPOSED AREA m^2	NUMBER OF PROPULSION SYSTEMS	UNIT MAIN DIMENSIONS m
MARCONI TYPE SAILS	1.3	1100	2	41.5 x 26.5
SQUARE RIG TYPE	1.8	794	2	18.0 x 22.0
COUSTEAU-PECHINEY ORIENTABLE, ASPIRATED CYLINDERS (TURBOSAILS)	5.5	260	2	25.5 x 5.1

Figure 11

Simulation of the Energy Savings Attainable on a Demonstration Ship of Approximately 4,500 Tons Displacement, Cruising at 12 Knots in an Equiprobable Wind of 25 Knots



MEAN POWER WITHOUT SAIL: 1,903 kW
MEAN POWER SAVING: 648 kW, i.e., 34 per cent
MEAN DAILY CONSUMPTION OF ENGINES WITHOUT SAIL: 9.51 tons/c
MEAN DAILY CONSUMPTION OF ENGINES WITH SAILS: 5.67 tons/day
MEAN DAILY CONSUMPTION FOR THE ASPIRATION: 0.44 tons/day
AVERAGE SAVING ON MEAN DAILY CONSUMPTION: 3.39 tons/day
AVERAGE FUEL SAVING: S2 = 32.3 percent
(for an equiprobable wind of 15 knots, average fuel savings would be 15 percent).

CONCLUSIONS

When compared to the lift coefficients of the best sails ever built (Marconi or square type, that is, those of the America's Cup or of the Japanese wind propulsion system), those of the Turbosails are 3.5 to 4.0 times superior and give the system a unique advantage for the economical propulsion of ships. With its greater efficiency, minimum deck space requirements and extreme simplicity of handling and control, the system has an exceptional aptitude for automation.

Fondation Cousteau, The Cousteau Society and the French aluminum company Cegedur-Pechiney have signed an agreement for the industrial development of the Cousteau-Pechiney System and its installation on commercial ships. Such ships will have electronically controlled engines and 'sails'; they will glide in the wind, run at a fixed operational speed, and reduce fuel costs.

At a time when the overall economic environment in the shipbuilding and marine transportation sectors is not particularly favorable, *Alcyone* will bring a gleam of hope which should induce engineers of all disciplines, naval architects, specialists of materials, shipbuilders and shipowners, to unite their efforts to define the ships of the 21st century and to give a new start to a key sector of the world economy. The alliance of the wind with hydrodynamics, electronics and computer sciences, should greatly help them in this task.

QUESTIONS AND ANSWERS

Q: It should be clear that reducing the sail area by four-fifths will not produce a coefficient of 5.0-6.0. Also, have you made any tests in humid, freezing air, as the perforated sheets may be covered in ice if the device is operated in freezing temperatures? In terms of acceleration, what is your personal experience regarding human performance? (Mr. C. A. Marchaj)

A: I agree absolutely with your first point. With regard to the second point, from our experience with *Alcyone* we have not been exposed to the icing of the system, but in another project, the system was working quite well under those conditions. Regarding acceleration, our experience on board *Alcyone* was very bad; of the ten people on board, four were seasick, two of them seriously.

Q: Have you any data on drag? (Admiral M. H. Khan)

A: We have some data on the effects of drag but at the speeds achieved it was relatively unimportant.

Q: I am interested in where the power figures for the rotor came from. (Mr. C. Palmer)

A: A student of Prof. Malavard wrote a dissertation on this subject and the figures come from his dissertation. I can send the justification for these figures to you if you wish.

Q: Can you tell us about the financial rate of return? (Mr. C. Palmer)

A: For construction of a piece of new equipment, the cost would be paid back in less than four years.

Q: Is hydrodynamic positioning important? (Mr. A. B. Thakur)

A: This is important and a suitable balance was reached with the aid of a computer.

Q: Can existing petroleum tankers be sail-retrofitted here in Manila under supervision of a manufacturer/designer? (Mr. M. dela Merced)

A: Every tanker to be sail-retrofitted is a particular case. However the main modifications concern the deck arrangement, to provide the relatively small space needed for installing a Turbosail or any kind of supporting mast.

Every sail-retrofitting operation starts with cautious control of the ship's stability for any load configuration, including the ballast. All calculations are made under the supervision and/or with the agreement of a ship classification company such as BV, DNV, ABS, etc. A general statement is that the larger the tanker (in terms of deadweight), the lesser the stability problems eventually met for retrofitting.

Being a nonprofit organization, Fondation Cousteau has entered into an agreement for retrofitting of ships with Turbosails, with the French Company Pechiney, which is of international renown in the light alloys sector and largely represented in South East Asia and in Australia. Since a proper agreement is reached with Pechiney, it may quite be possible to carry out retrofitting of petroleum tankers in Manila.

Planform Effect of a Number of Rigs on Sail Power*

C. Anthony Marchaj**

INTRODUCTION

While much is known about high performance sailing rigs for racing (mainly the Bermudan rig), little or no systematic research has been carried out into other traditional, commercial sail configurations. Thus, it is difficult when selecting a sail plan for a boat, to determine with certainty whether a proposed rig is more efficient (for a given sail area) than another, either anticipated or already existing.

Since there are considerable differences of opinion as to the merits of various forms of sail, this research, based on theoretical analysis and wind tunnel testing, will enable the advantages and disadvantages of various sail configurations to be better understood and predicted with reasonable accuracy. It will also indicate directions for improvement of traditional rigs, while guiding the selection of appropriate sail configurations for fishing and working boats. Planforms of all rigs tested are given in Figure 1. Plate 1 illustrates a wind tunnel test using a dipping lug rig.

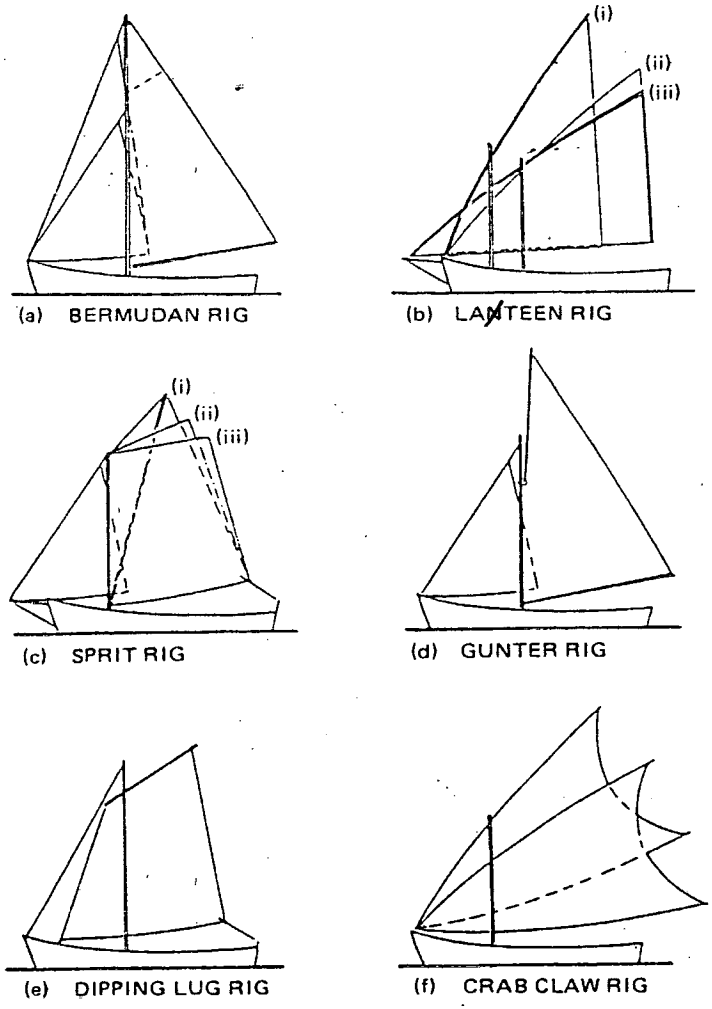
The whole problem of wind tunnel testing, and how tests are conducted, is closely allied to what is hoped to be gained from the test. If determination of the forces on a sail under normal sailing conditions is required, then the logical thing to do is to go on a sailing boat, and measure those forces in action — a task which, although difficult and time consuming, is not insuperable. Testing in a wind tunnel, however, allows a systematic variation of important geometric and physical factors, which can be held under

* In collaboration with J. Howard-Williams.

** Independent aerodynamic research scientist and chartered engineer. Mr. Marchaj is the author of three books and numerous articles on sailing. His *Vulnerability of Sailing Boats to Capsize in Rough Weather* was recently awarded the Royal Institution of Naval Architect's silver medal.

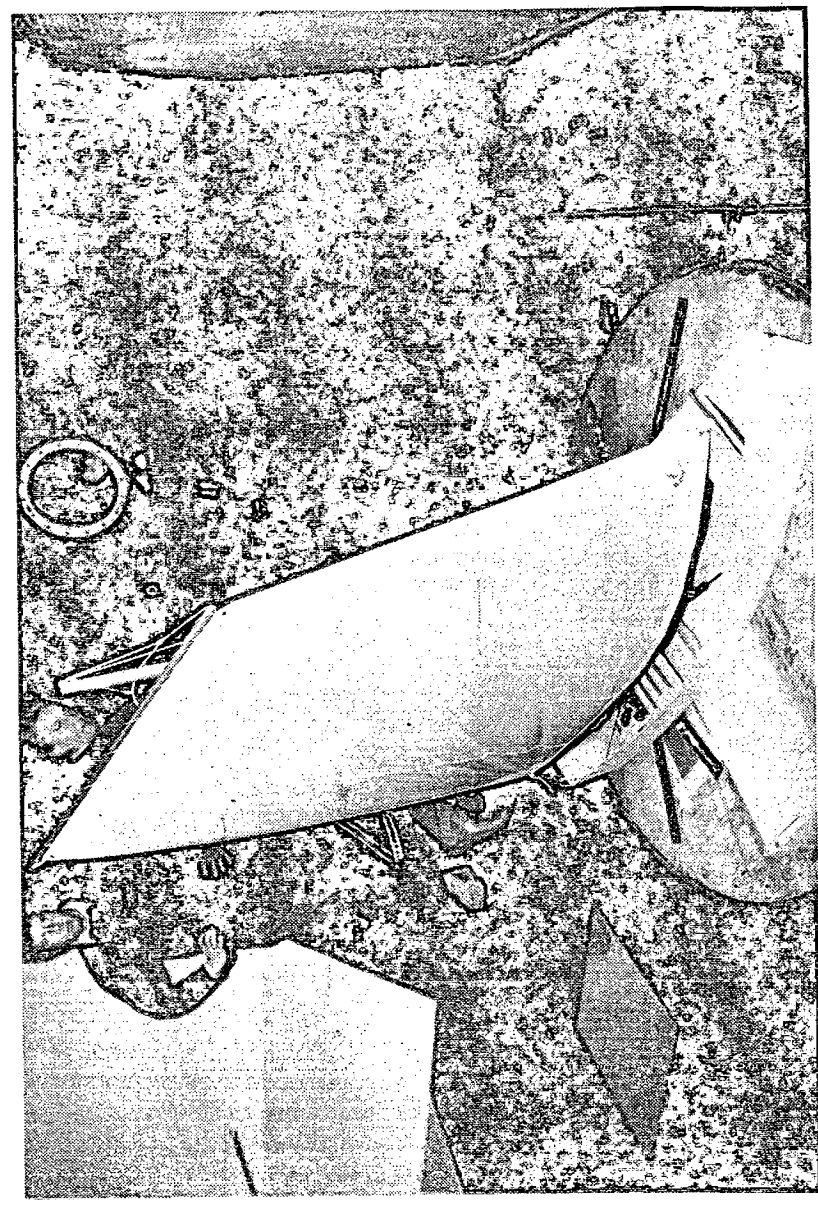
Figure 1

Planform of Sailing Rigs Tested



(a) Bermudan rig with and without large and small jibs; also how much of the head of the mainsail was removed.
(b) Three different shapes of lanteen sail.
(c) Sprit rigs of three different aspect ratios.
(d) Gunter rig.
(e) Dipping lug.
(f) The same crab claw sail was set at varying angles.

Plate 1



A view of the (3.5m x 4.5m) working section of the wind tunnel at Southampton University. The control room is to the left behind the small circular observation window. In the illustrated example, a dipping lugsail is being tested in a close hauled attitude.

close control. Thus, one may rightly expect dissimilar results when sail area is kept constant but changes are introduced into the sail plan, that is, sail distribution, aspect ratio, etc.

From Figure 2, it is evident that rigid control is necessary over any experiment, whether conducted full size or on a model. It is difficult, if not impossible, to determine the effect of changing one factor, if at the same time one or more other factors alter. The wind tunnel offers great advantages in this respect: good control of the tests implies repeatable results which can be presented simply and therefore, understood more easily. In addition, information can be obtained comparatively quickly. The use of a model which is not the same size as the original must inevitably introduce limitations on the results, and the art of wind tunnel testing is largely to obtain the representative model results with the minimum of effort. Even if exact quantitative data may not always be obtainable because of scale effect, absence of wind gradient, the unsteadiness of real wind, etc., all important trends can easily be established. Otherwise the designer must rely on guess work, or full-scale, long-term observations of vessel behavior in conditions where everything is real and natural, but nothing can be precisely measured and controlled.

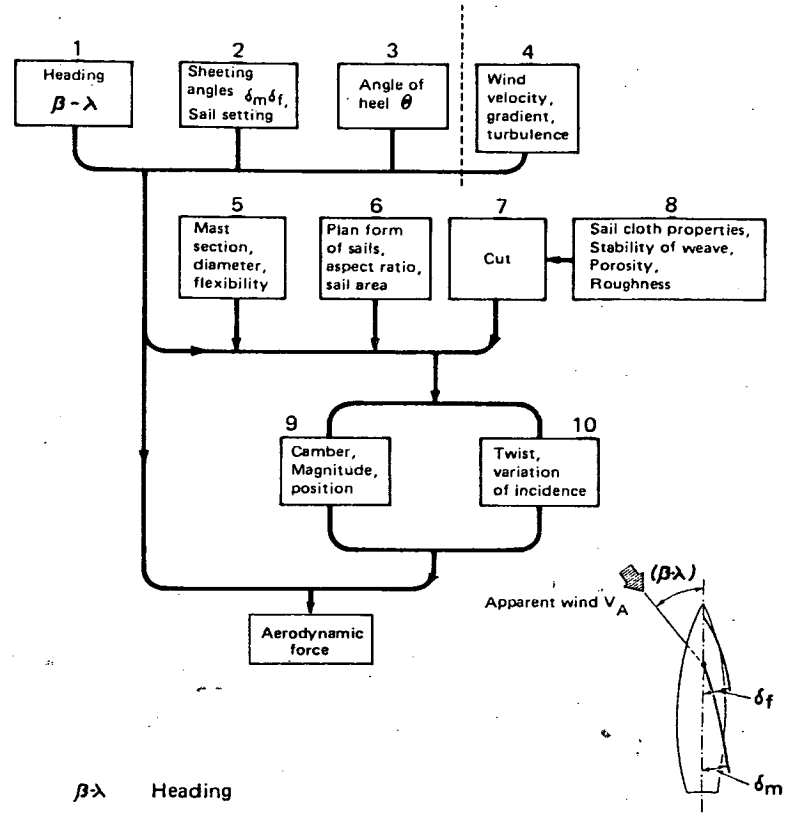
We do not intend to enter into a detailed discussion of all the factors which can influence the forces developed by a sail, but Figure 2 will give an indication of their complexity. Figure 2 shows only the main relationships, and much has been omitted for the sake of simplicity. One such omission is that of 'feedback', the way in which a factor affecting another is in turn affected by it. As an example of how the diagram works, consider the case of the mast. The mast has a profound effect on the flow over a whole sail and, in addition, a mast has its own pressure distribution around it. It can further influence the sail shape (camber and twist) by bending.

Some of these effects are illustrated in Figure 3, which shows the measured lift and drag coefficients (C_L and C_D) for three triangular sails using masts of identical diameter. The sails were rigid and had the same camber and almost zero twist. A small part of the differences between these results can be attributed to the different sail planforms (in the absence of the masts), that is, the aspect ratio.

Classic aerodynamic theory relates induced or vortex drag (drag due to lift) directly to aspect ratio. It can be demonstrated, for example, that a glider's performance can be improved by increasing the aspect ratio of its wings. There is no need to test it over and over again to be certain that it must be so. Rigs of sailing boats also produce induced drag. The theory of induced drag as developed in relation to wings, however, does not apply to sails without limitation, and Figure 3 illustrates the point. By virtue of

Figure 2

Factors Affecting Aerodynamic Forces on Sails[a]

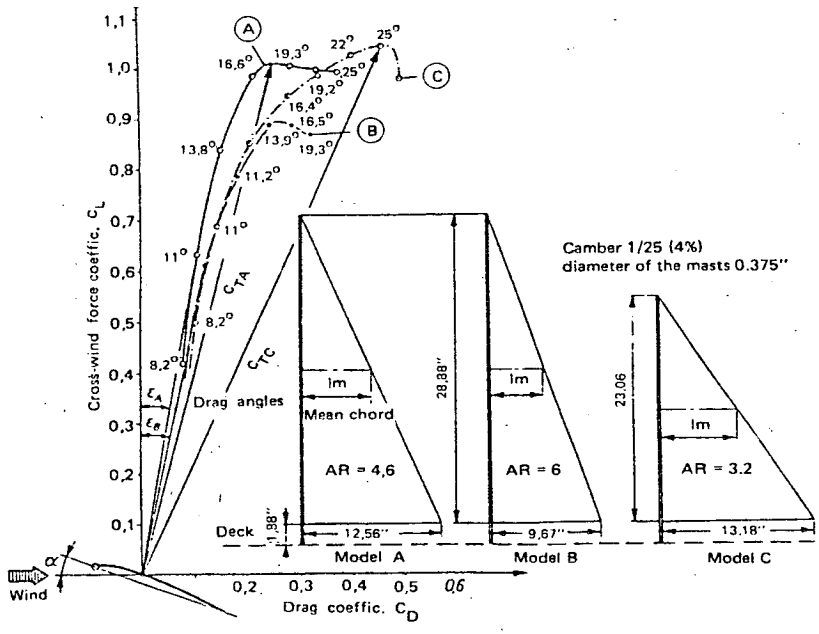


$\beta\text{-}\lambda$	Heading
V_A	Apparent wind velocity
θ	Angle of heel
δ_f	Sheeting angles, foresail
δ_m	Sheeting angles, mainsail

a/ Some of these factors are determined by design (sail cut, cloth properties). Some depend on crew expertise, and some depend entirely on the wind (gradient, velocity, turbulence). The planform and mast effects are discussed in this paper.

Figure 3

Effect of Mast Diameter



The effect of mast diameter (constant) on sail characteristics (crosswind, or lift coefficient versus drag coefficient) which invalidates expectations based on aspect ratio alone.

its highest aspect ratio (AR), model B should, on the basis of theory (see Equation 1), produce the best lift/drag (L/D) ratio (Marchaj, 1982).

induced vortex drag:

$$C_D = C_d + \frac{K \; C_L^2}{\pi \, AR} \quad \text{..... Equation 1}$$

where CD = total drag coefficient
Cd = section (form) drag coefficient
CL = lift coefficient
K = constant, depending on planform of the wing (K = 1.0) for elliptical planform; usually greater than 1.0 for other planforms

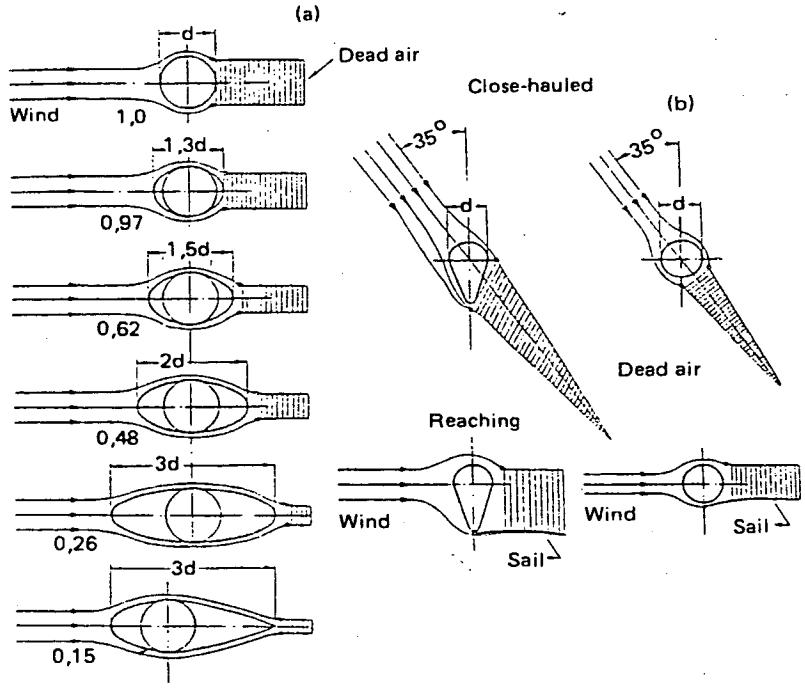
It will be noted that AR is in the denominator of the expression, determining the induced part of the total drag. The higher the AR, the lower the induced drag contribution to CD. When, however, one considers the L/D ratios reflected in Figure 3 by the so-called drag angles E_A and E_B (given by tangent lines to the relevant curves), it becomes clear that planform B does not occupy the position of merit one might expect by virtue of having the largest AR. Thus, rig B would be less efficient than rig A. This can be attributed to the effect of the wake behind the mast, which adversely affects the all-important flow round the leeward side of the sail. The ratio of mast diameter to mean sail chord (Im) is of considerable significance here. Since in each test model the mast diameter was the same, Im is larger for the high AR rig B (0.078) than for rig A (0.060), and therefore the adverse effect of the mast on rig B is correspondingly greater.

This example illustrates possible pitfalls for those who are tempted to apply classic aerodynamic theories directly to sailing boats. After all, a sail is not a wing. On the other hand, a sail is not just a piece of canvas supported by mast and ropes, but a propulsive device which, to be effective, must take up a prescribed shape when loaded by the wind. In other words, the size of sail is not the only factor which matters.

It has been found that air prefers to negotiate smooth streamlined bodies, preferably offering to the flow a small frontal area relative to their streamwise length. Figure 4 shows the form drags associated with various mast sections having the same frontal area, tested at the same wind speed. This drag arises from a characteristic of airflow: it can smoothly follow a contour having a forward-facing slope, but has great difficulty in following a backward-facing slope. At some point the flow no longer follows the profile, but separates, forming a turbulent wake, the size of which is an

Figure 4

Mast Drag



Form drag of various mast sections resulting from separation of flow from the surface, and wake (dead air) behind the mast.

indication of the form drag which is present. Such drag is a measure of energy taken out of the flow (wind) and lost to the disadvantage of rig performance in terms of driving force. This implies that efficient generation of a driving force on the sails is not compatible with large energy wastage in the form of extensive wake flow. In other words, 'thin wake attached flow' is the general objective which the sailmaker or rig designer should keep in mind.

Figure 4(a) shows how streamlining can considerably reduce drag from that of the basic circular section — but not under all conditions. Fishing and working boats do not sail closer to the apparent wind than 25 to 35 degrees, and usually sail at greater angles than these. In such circumstances, the greater portion of the leeward side of the sail will be adversely affected by a large wake behind a streamlined mast (see Figure 4(b)). Thus we must conclude that a circular mast is better and certainly more practical than a streamlined one, unless the latter rotates with the sail. For this reason, spars of a circular section were used with all models tested in this wind tunnel series.

So far, we have attempted to give some idea of the difficulties in interpreting wind tunnel test results. It might be relevant now to discuss briefly the basic principles of sail testing, and to show how the aerodynamic characteristics of sailing rigs can be measured and compared. Figure 5 should help an unfamiliar reader to interpret wind tunnel results, presented in standard aerodynamic terms such as lift (L) and drag (D), and to convert them into the driving and heeling forces (F_R and F_H respectively), which are directly responsible for a sailing vessel's motion.

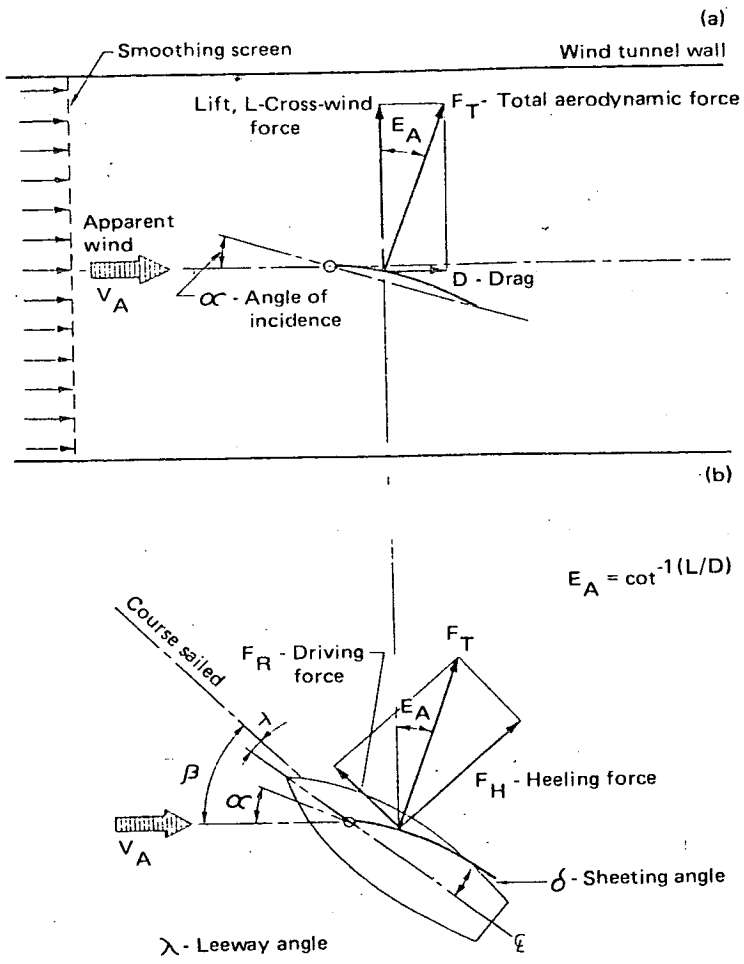
WIND TUNNEL TESTING

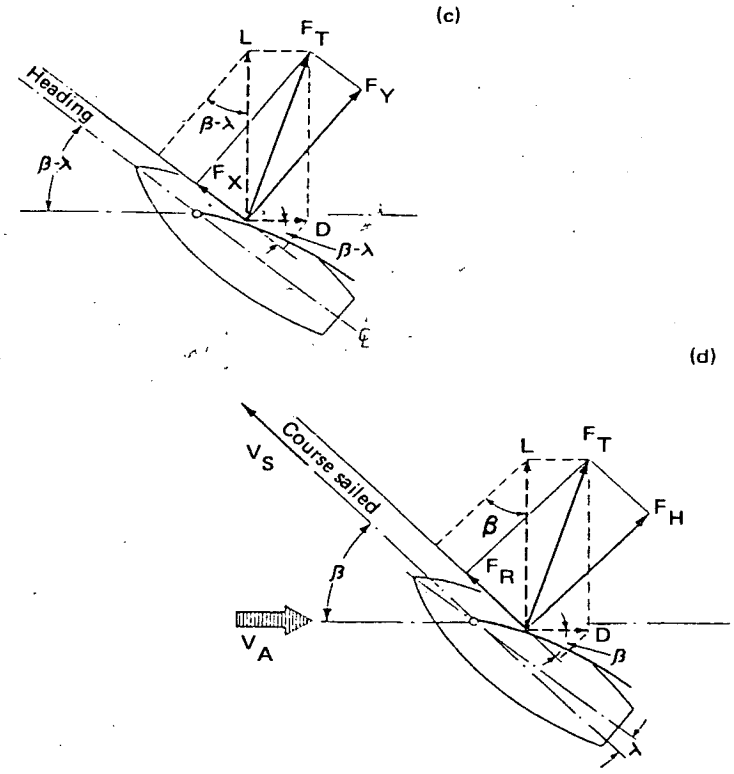
The wind tunnel at Southampton University, where the tests on the various rigs were conducted, is a tubular closed-return structure through which a stream of air is kept in motion by means of an airscrew driven by an electric motor. The maximum wind speed which can be controlled precisely is about 9 m/sec[3] (30 ft/sec, 18 knots, or about force five on the Beaufort scale). The working section of the wind tunnel, as illustrated in Plate 1, can accommodate models with a mast height up to about 2.5 meters.

A model of a representative fishing boat hull, consisting of that part which is above the waterline, together with the rig, was attached to a turntable (Figure 6), which can be rotated and controlled from outside the wind tunnel to alter the heading angle of the hull ($\beta - \lambda$) to the apparent wind. The turntable is connected to a pontoon floating in a water tank built below, but integral with the floor of the tunnel. The turntable effectively eliminates

Figure 5

Definitions Used in Wind Tunnel Testing

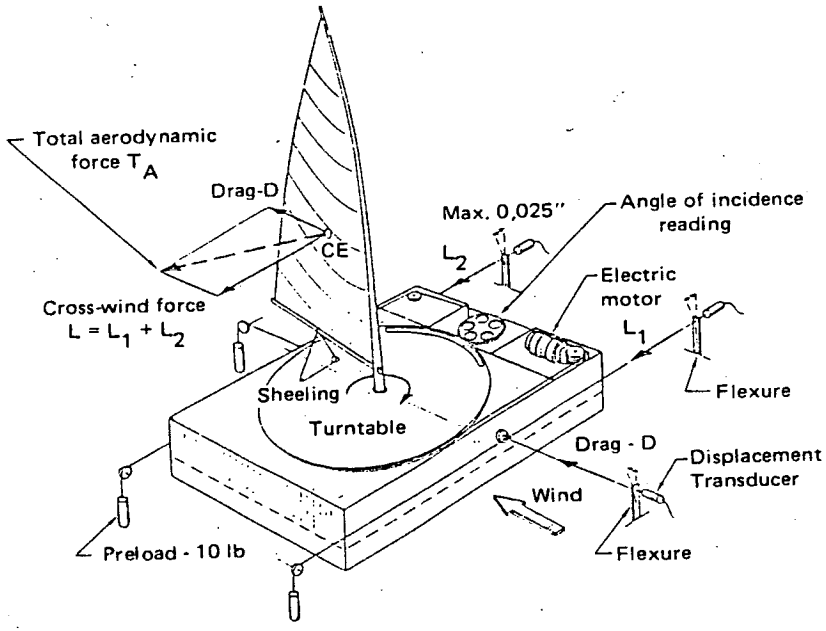




The total aerodynamic force (F_r) may be considered to act solely through the center of effort (CE) (see also Figure 6). The magnitude of F_r and its direction of action can be established by measuring in the wind tunnel its two components, namely lift (L) and drag (D); drag is measured in the same direction as the apparent wind (V_A), and lift at right angles to it. Lift is so called because the most familiar example of a similar force is the upward component acting on an aircraft's wing (despite its name, however, lift does not necessarily always act upwards, for example on a rudder or a sail). The two alternative components in which every sailor is directly interested are driving force (F_R) and heeling force (F_H) which form another combination to make up the same total aerodynamic force (F_r). The driving force (F_R) shown in the direction of the course sailed, propels the boat; the heeling force (F_H) at right angles to the former causes sideways drift and heel of the hull. Since the leeway angle (λ) is not the same for every boat and its value depends not only on hull shape but also on the course sailed (β) and boat speed (V_S), it became common to present wind tunnel results in a slightly different way from that shown in Figure 5(b). This is illustrated in Figure 5(c) where the two components (F_x) and (F_y) of the total force (F_r) are given parallel and perpendicular to the hull centerline, that is, boat heading (β-λ) instead of related to the course sailed (β) when they become F_R and F_H respectively as shown in Figure 5(d).

Figure 6

Balance System



The wind tunnel balance system as designed by the author some years ago. Apart from lift and drag measurements, the vertical position of the Center of Effort can be established by measuring the heeling moment.

the problem of sealing between the model and the balance system, and also provides a simple and relatively stiff form of suspension. The pontoon is controlled horizontally by springs, the deflections of which are proportional to the forces which are measured electrically.

The total force components L and D are measured for known sheeting angle (δ) at a given apparent wind speed (V_A) either for a given heading angle ($\beta - \lambda$) as shown in Figure 5(b), or for angle of incidence (α) of the sail relative to the wind direction (Figure 5(a)) in the case when one sail only is investigated. Heading angle ($\beta - \lambda$) or incidence angle (α) is progressively altered by increments of, say, 2.5 degrees, so that ultimately, a graph may be plotted to show how lift and drag vary with heading or incidence angles.

Presentation of Test Results

A graph called a polar diagram is produced in Figure 7(a) and represents the forces on a single triangular sail with sail area (S_A) = 2.4 sq m (18.1 sq ft) and at an apparent wind speed (V_A) = 8.9 m/sec (29.3 ft/sec). Presentation like this is of basic practical and theoretical importance. It enables us to find the direction and magnitude of the total aerodynamic force (F_T) at any selected angle of incidence. These angles are inscribed along the polar diagram curve. The two sketches accompanying Figure 7(a) show the measured forces (magnitude and direction of action) developed on the sail, tested at angles of incidence of 27.0 and 37.5 degrees.

The actual magnitude of lift and drag, as well as the total force (F_T) for a given sail configuration (of given camber, twist, planform, aspect ratio, etc.) are known by both theory and experiment to depend on the sail area (S_A) and the so-called dynamic wind pressure (q) = $\frac{\rho V_A^2}{2}$ (where ρ is air density) in lb. sec^2/ft.^{4} ; q, the standard wind pressure at sea level, is 0.00119 V_A^2, thus:

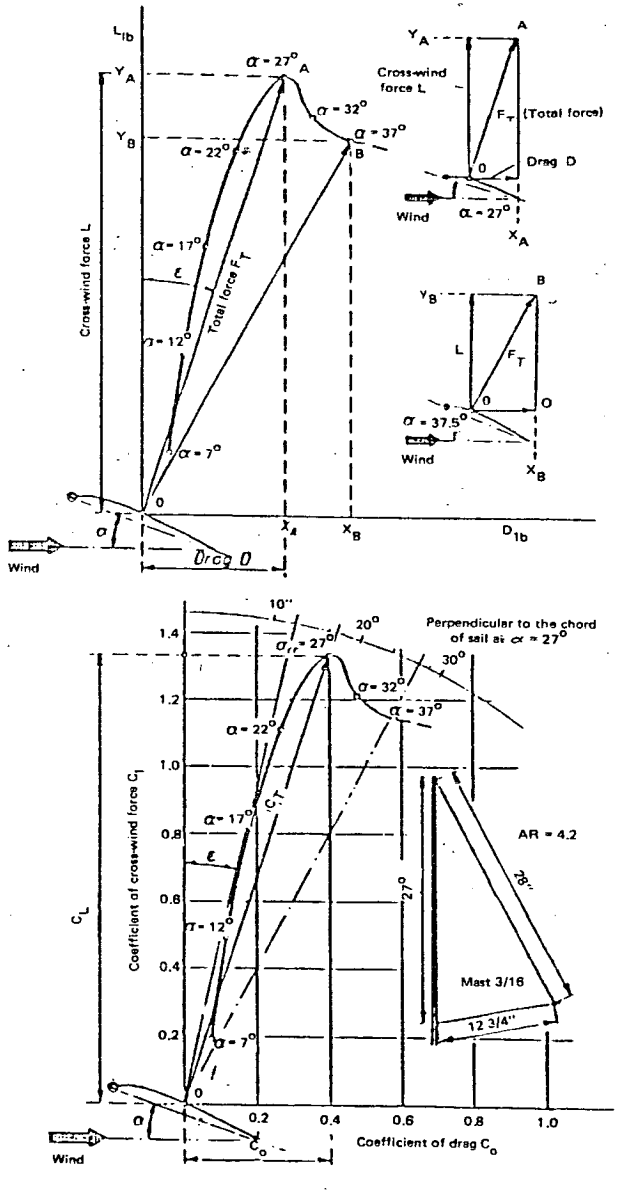
$$L = C_L \times q \times S_A = 0.00119\, C_L \times S_A \times V_A^2 \quad \text{..... Equation 2}$$

$$D = C_D \times q \times S_A = 0.00119\, C_D \times S_A \times V_A^2 \quad \text{..... Equation 3}$$

Symbols C_L and C_D, called respectively lift coefficient and drag coefficient are, in fact, empirical shape factors. They can be determined by dividing the measured values of lift and drag by the dynamic wind pressure and sail area, that is:

Figure 7

Polar Diagrams of Lift and Drag: (C_L and C_D)



Result of wind tunnel measurements presented in the form of a polar diagram of forces (L and D) and coefficients (C_L and C_D).

$$C_L = \frac{L}{q \times S_A} = \frac{L}{.00119\ V_A^2 S_A} \quad \text{..... Equation 4}$$

$$C_D = \frac{D}{q \times S_A} = \frac{D}{.00119\ V_A^2 S_A} \quad \text{..... Equation 5}$$

Thus, coefficients C_L and C_D represent forces that would be developed at unit of wind pressure (q) on unit of sail area (S_A). The graph in Figure 7(b) shows the coefficients of sail forces given in the graph of Figure 7(a).

One of the essential advantages of plotting a polar diagram of sail coefficients instead of sail forces is that we can readily compare results of tests on any arbitrary sail form obtained at different wind speeds, and thus study the reasons why, and how much, one rig is more efficient than another. Obviously, it is desirable to have some relatively simple means of making an assessment of the results of such tests by considering sails on their own merits, that is, without tentatively considering the hydrodynamic effect of the hull on a vessel's performance.

What follows is a description of some methods of evaluating the relative merits of different sail plans. Of course, the answers so obtained are only comparative, and indicative of trends, without at first attempting to assess the speed performance of the vessel.

CRITERIA OF SAIL POWER

When estimating the merits of a sail as an airfoil, or as a lift-generating device, we may regard drag as the price paid for lift (see Equation 1). The drag angle (ε_A), distinguished as the angle between lift (L) and total aerodynamic force (F_r) may serve as an index of aerodynamic efficiency of the sail (see Figure 5(b)). This angle specifies the direction of F_r and, if drag could be reduced without altering the lift magnitude, the sail would be more efficient, particularly in windward work. Clearly, the total aerodynamic force would then be inclined more towards the bow; therefore the driving force (F_R) would be a larger fraction of the undesirable heeling force (F_H) which the hull must somehow cope with (Marchaj, 1982).

Close Hauled

Let us start with the two lanteen rig configurations (i) and (iii), shown earlier in Figure 1. Figure 8 gives the polar diagrams of these two rigs. Take

into account the three basic sail performance factors:

the driving force component F_x or F_c;
the heeling (side force) component F_y or C_y; and
the heading angle $(\beta\text{-}\lambda)$.

We may argue that if, at a particular angle of heading, an alteration of the sail plan is accompanied by an increase in the driving force component, without a corresponding increase in the heeling (side force) component, then a better performance to windward should result.

This concept is presented in Figure 8, where it will be seen that the polar curve of lanteen rig (i) is bodily shifted to the left (towards lower drag) relative to that of lanteen rig (iii).

In a typical close hauled condition, at a heading angle of 33 degrees to the apparent wind, both rigs develop the same lift coefficient (C_L) = 1.36, but lanteen rig (iii) produces higher drag. As a result, the drag angle (ε_x) of lanteen rig (iii) is much greater; consequently, its driving component is about 37 per cent less than that of lanteen rig (i). Since the differences in the heeling (side) force components are relatively small (about 8 per cent), one may expect that lanteen rig (i) should be more efficient to windward than lanteen rig (iii). Evidently, the ratio of driving force to heeling force (C_x/C_y) is higher, more favorable for lanteen rig (i) than for lanteen rig (iii). Thus, the hull will be less heavily burdened than when balancing undesirable heeling forces, an action which always incurs hydrodynamic penalty and therefore slows the boat.

Figure 9 represents two polar diagrams, one for the dipping lug and one for the sprit rig (i). Here again, one polar curve is shifted bodily towards lower drag relative to the other. However, at the same selected heading angle of 32.8 degrees, these two rigs produce different lift coefficients but at the same drag angle. The dipping lug generates about 27 per cent more driving force, but its heeling force component is also higher by exactly the same amount.

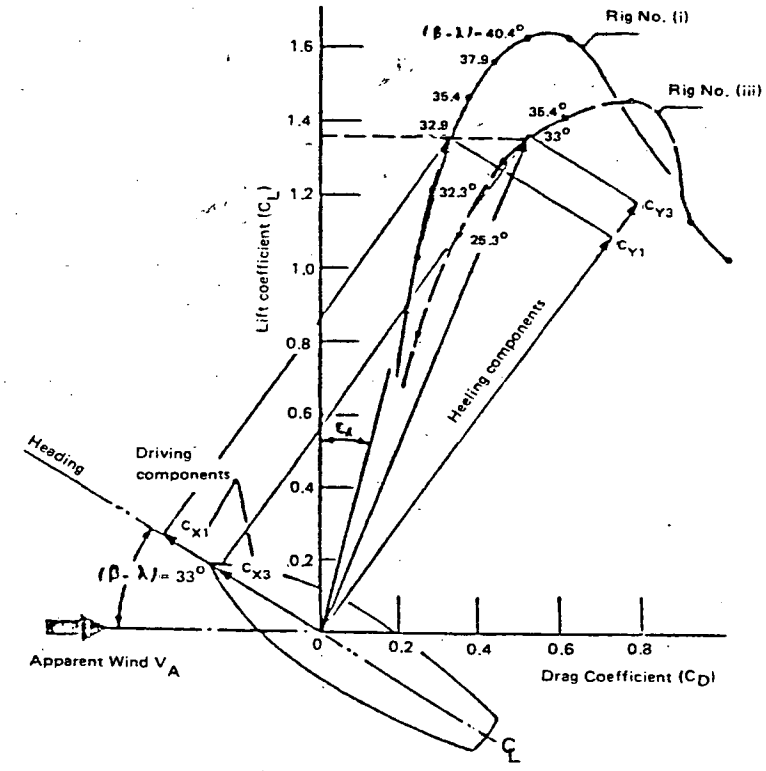
Is the dipping lug thus more efficient than sprit (i)? Before the answer to this question is verified in a subsequent section, let us consider the sail criteria for reaching and running.

Reaching

When the boat begins to bear away from the close hauled condition, the windward criterion discussed above becomes gradually less stringent. Sails generate less and less heeling force off the wind, and hence the ratio of C_R/C_H or C_X/C_Y increases. In the beam reaching attitude shown in

Figure 8

Lift and Drag of Lanteen Rigs, Nos (i) and (iii)



This shows the principle of windward performance interpretation. An analysis of the graph can be carried out, no matter whether rig characteristics are given in terms of actual forces or their coefficients. The horizontal components Fx and Fy of the total aerodynamic force, acting parallel and perpendicular, respectively, to the hull center line, can be calculated from the expressions:

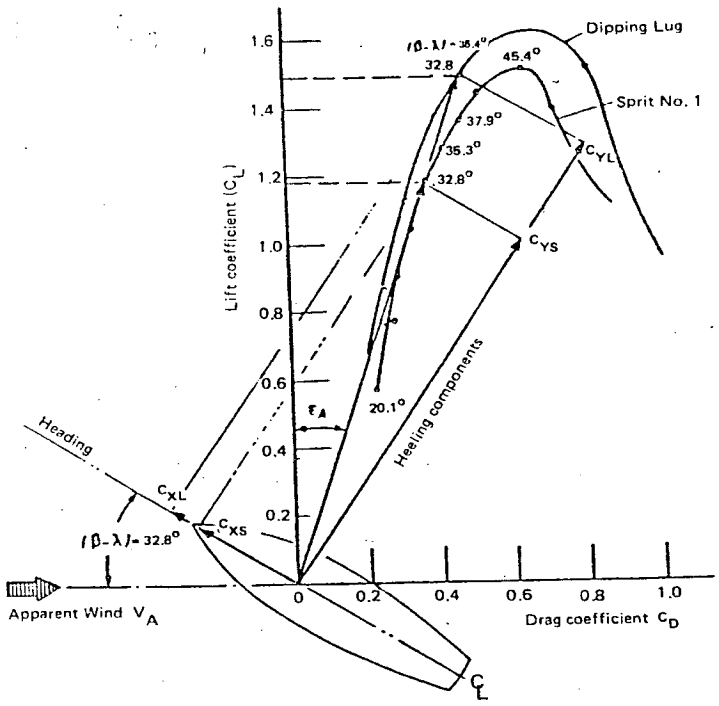
$Fx = L \sin(\beta\text{-}\lambda) - D \cos(\beta\text{-}\lambda)$ . . . . . Equation 6
$Fy = L \cos(\beta\text{-}\lambda) + D \sin(\beta\text{-}\lambda)$ . . . . . Equation 7

Cx and Cy which are coefficients of Fx and Fy forces can be established in a similar manner to the C_L and C_Y coefficients (Eqs 4 and 5); e.g.

$$Cx = \frac{Fx}{.00119\, V_A^2\, S_A} \quad \text{. . . . . Equation 8}$$

Figure 9

Lift and Drag of Dipping Lug and Sprit Rig No. 1



This shows one of the windward performance criteria when, at the same β and ε_A angles, one rig produces higher driving power (Cx) but also higher heeling force (Cy) by the same percentage. According to the speed performance prediction, the dipping lug is marginally faster close hauled than the sprit; V_S = 3.5 and 3.4 knots, respectively.

Figure 10, the relatively small heeling force component C_H or C_Y becomes a somewhat irrelevant factor; instead, the driving component C_X or C_R dominates (the higher the better). And since $C_L \simeq C_R$, the higher the lift the sail develops, the more powerful the rig.

In further reference to Figures 8 and 9, it can be seen that the polar curves for lanteen rig (i) and the dipping lug are bodily shifted upwards towards higher lift. One should therefore expect that these sails will be more efficient in reaching conditions than the lanteen rig (iii) and sprit (i), to which these are compared. In reaching conditions, maximum speeds are attained at heading angles of about 90 degrees and with sails sheeted for maximum lift.

Running

On downwind courses, sails are usually set at an angle of incidence of about 90 degrees relative to the apparent wind. With the mast supported by normal rigging, this can sometimes be restricted by fouling of the sail and boom with the shrouds. In such circumstances, the only criterion for sail efficiency is maximum drag of the rig, because the driving force is equivalent to drag. In practical terms, this means that maximum possible sail area should be exposed to the action of the wind. Since drag is largely independent of the sail planform, all sails, no matter what shape, should produce the same drag coefficient at an angle of incidence of 90 degrees, provided that their area is not distorted by twist or other deformations, such as that shown in Plate 2. Twist reduces the projected sail area, and hence the drag coefficient.

Summary of Sail Criteria

Bearing in mind the sail criteria discussed so far, different rigs may be ranked roughly on three basic courses: close hauled, reaching and running, by comparing their ability to produce the highest driving component without incurring hydrodynamic penalties (Marchaj, 1979, 1982).

Table 1
Sail Criteria for Different Headings

Heading	Criteria
Close Hauled	Higher L/D ratio Lower drag for the same lift at the same heading angle Higher $C_R(C_X)$ component at the same C_X/C_Y or C_R/C_H ratio
Reaching	Higher C max
Running	Higher C_D Largest possible sail area exposed to the wind action

OVERALL POTENTIAL DRIVING POWER OF RIGS TESTED

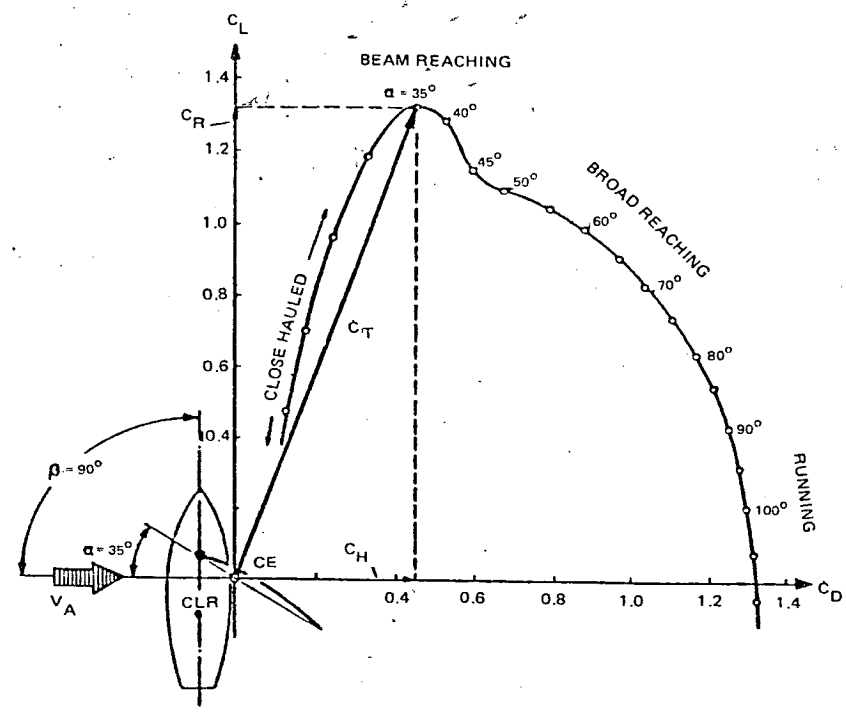
Subject to the restrictions presented in Table 1, a plot of driving force component (C_X) against heading angle, ranging from close hauled ($\beta - \lambda = 20^\circ$) to running ($\beta - \lambda = 180^\circ$), may be used as a quick measure of the potential performance of different sails.

This is shown in Figure 11 in which the Bermudan rig (mainsail and large jib) is compared with the crab claw rig. The point of intersection of one curve by the other, marked 'O', indicates that at certain angles, one rig loses its superiority. In this particular case, the Bermudan rig becomes inferior to the crab claw at $\beta - \lambda \simeq 42$ degrees. The totality of the area under the C_X curve, when considered over the whole range of heading angle, represents a form of mean value of driving force, and hence may be used as a yardstick of sail power.

The results for all rigs tested are shown in Figure 12, which should be read in association with the key below it. It will be seen, for example, that the crab claw rig has a marked overall superiority, with a value twice that of the poorest lanteen rig, lanteen rig (iii), and about 25 per cent better than most of the others. The Bermudan rig, which appears to the majority of racing yatchsmen to be the epitome of progress towards speed performance, is by no means the best rig tested. Besides the crab claw, lanteen rigs (ii) and (iii), the Gunter and the lugsail, all come out of the tests as more powerful on some courses.

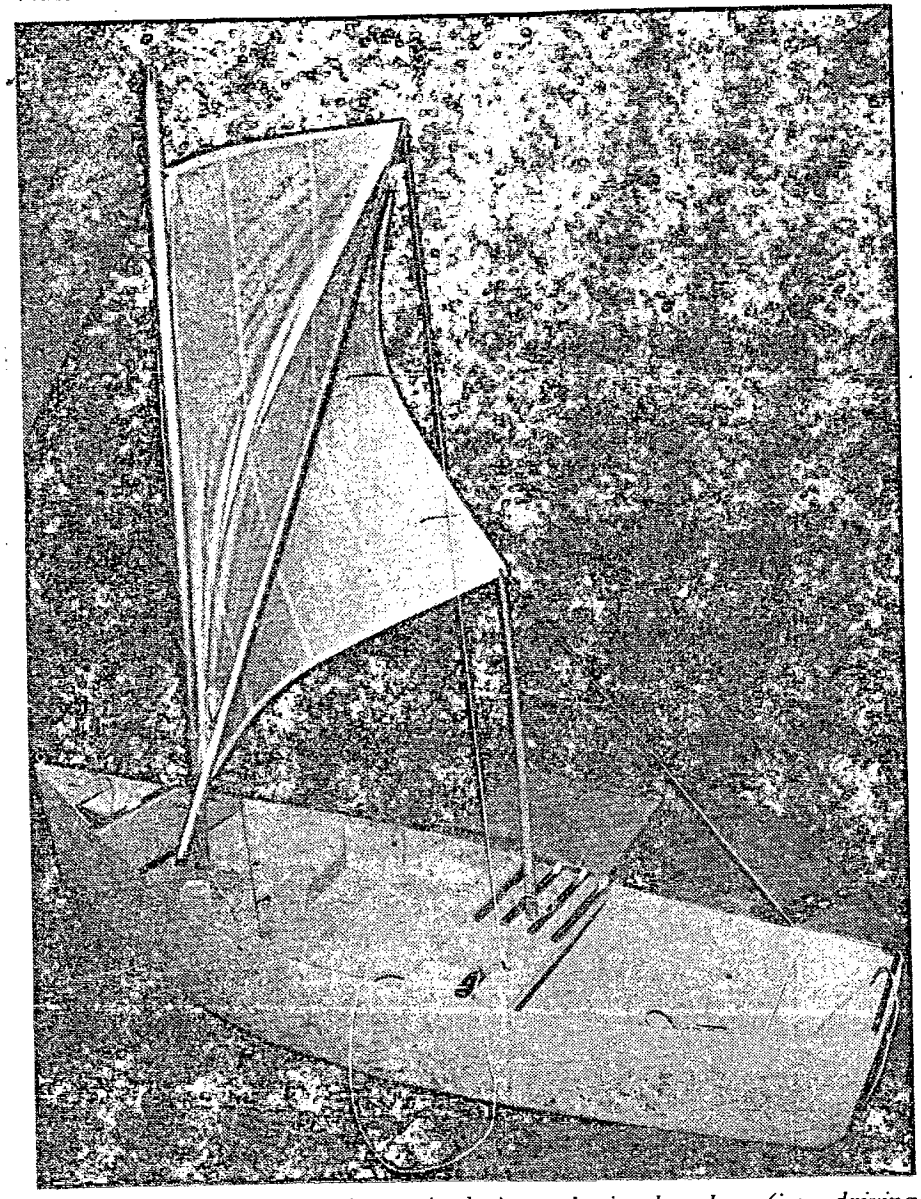
Figure 10

Lift and Drag



Depending on the course sailed (heading), the sail(s) must be trimmed to operate over a particular part of the polar diagram. In reaching conditions, they should be sheeted to give maximum lift (which is usually about the same as the driving component).

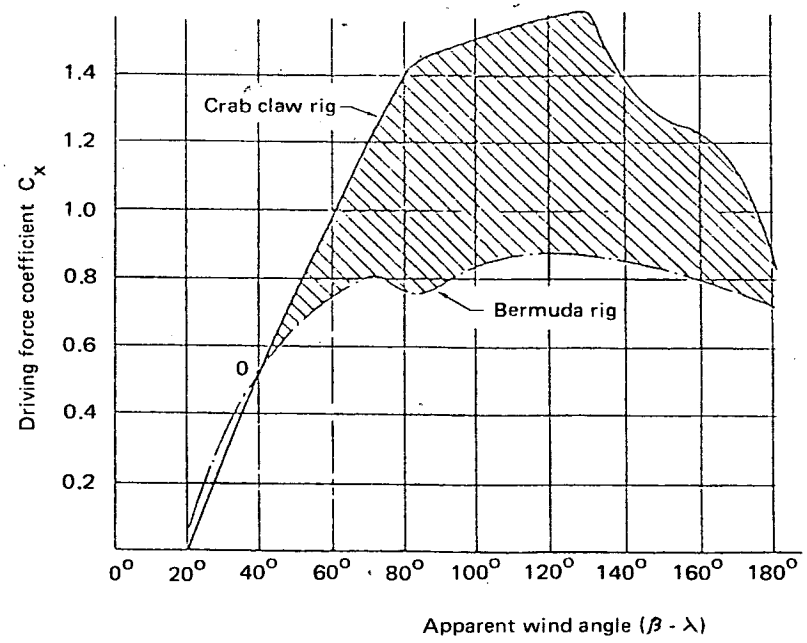
Plate 2



Sprit Rig (iii) in the running attitude is producing less drag (i.e., driving force when running) than it might, due to twist and other distortions preventing the whole area being exposed uniformly to wind action. If the sail were to be properly set, $C_D \simeq 1.2$.

Figure 11

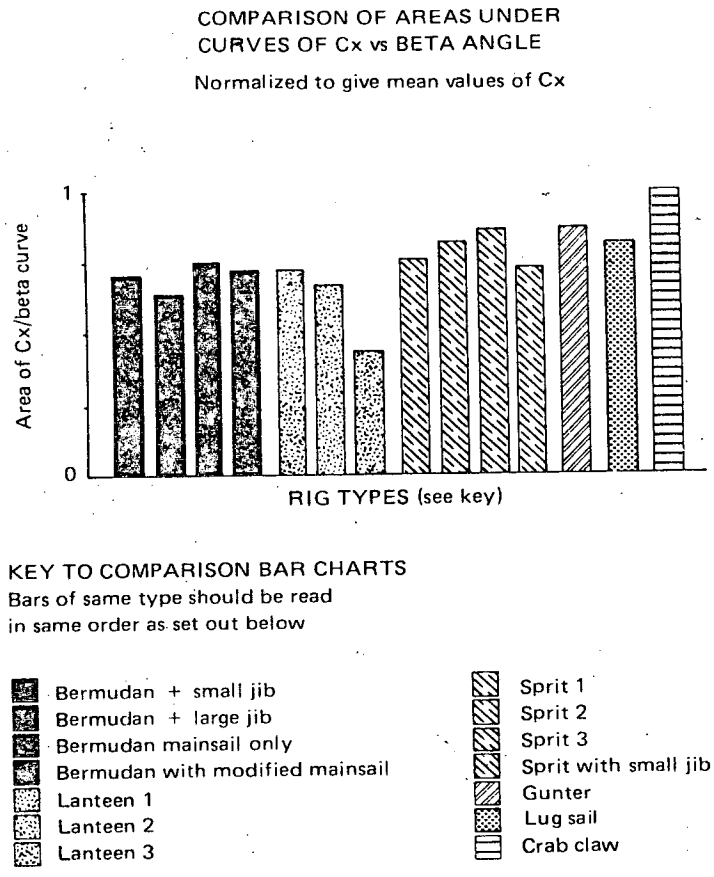
Sail Power Potential (1)
The Potential Power of the Crab Claw Compared with the Bermudan Rig.



The hatched area represents the margin of superiority of the crab claw rig over the Bermudan rig at angles ranging from 40 degrees to 180 degrees.

Figure 12

Sail Power Potential (2)



Comparison of potential power areas (see Figure 11) obtained by plotting Cx against β-λ for all rigs with their modifications.

Figure 13 illustrates the magnitude of the driving force component (C_X) for three representative points of sailing, selected for closer speed performance study. These are:

- close hauled = 30 degrees
- reaching = 60 degrees
- running = 150 - 180 degrees

SPEED PERFORMANCE PREDICTION

To establish the relative merits of rigs tested in terms of speed, and to check the validity of sail criteria discussed earlier, we carried out a performance prediction program of the sailing speed of two representative artisanal fishing boats (Gifford and Partners, 1985).

Hull Forms

A displacement type of hull with a length/beam ratio of five was chosen as a typical plank-built boat found in many parts of the world. The hull resistance data were derived from tank tests by Gifford and Partners on a selection of Indian artisanal fishing boat hulls. The hull was fitted with a shallow keel and had the following basic measurements:

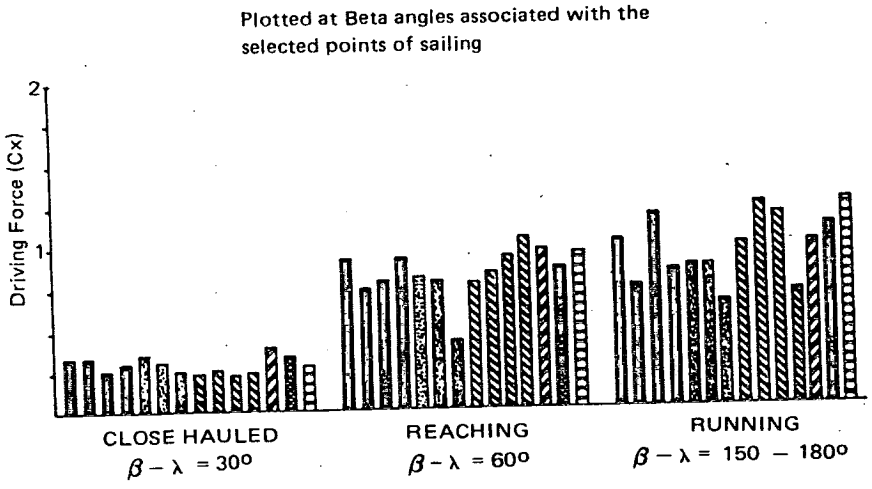
Length (L)	=	8.8m (28.9 ft)
Displacement ($\triangle$)	=	2.5 tons
Sail area (S_A)	=	$20m^2$ ($215\ ft^2$)
Displacement/length ratio taken as $(0.01L)^3$	≃	104

A slender stabilized canoe was also selected, deliberately to provide a contrast with the other hull. It was assumed that this canoe would normally be fitted with some form of stabilization which would not increase hull resistance (for example, a *proa,* with the float to windward). To achieve the close hauled performance modelled, the canoe would have to be fitted with a dagger board or leeboard. Basic measurements were:

Length	=	9.0m (29.5 ft)
Displacement ($\triangle$)	=	1.5 tons
Sail area (S_A)	=	$20m^2$ ($215\ ft^2$)
Displacement/length ratio taken as $\triangle(0.01L)^3$	≃	58.5

Figure 13

Comparison of Driving Force



Comparison of driving forces of all rigs when close hauled, reaching and running.

Speed performance analysis was done on two simplified assumptions. First, the effect of waves was not considered, so that the predictions of speed made good to windward (V_{mg}) are likely to be optimistic compared with real conditions. Secondly, the added resistance due to heel angle was not considered. It is known, however, that the effect is relatively small up to about 15 degrees of heel. As distinct from pleasure yachts, such heel angles are seldom exceeded in practice by working or fishing boats.

Computer Printouts

Computer-generated polar plots of speed performance for a 2.5 ton displacement type of heavy boat, driven by the rigs tested, are given in the Annex. From these following data can be derived:

V_S	Boat speed in knots
V_{mg}	Boat speed made good to windward
γ	Angle of true wind to heading
$\beta - \lambda$	Heading angle

Predicted speeds against true wind angle (γ) were calculated for the true wind speed (V_T) = 12.0 knots (6.2m/sec).

Interpretation of Results

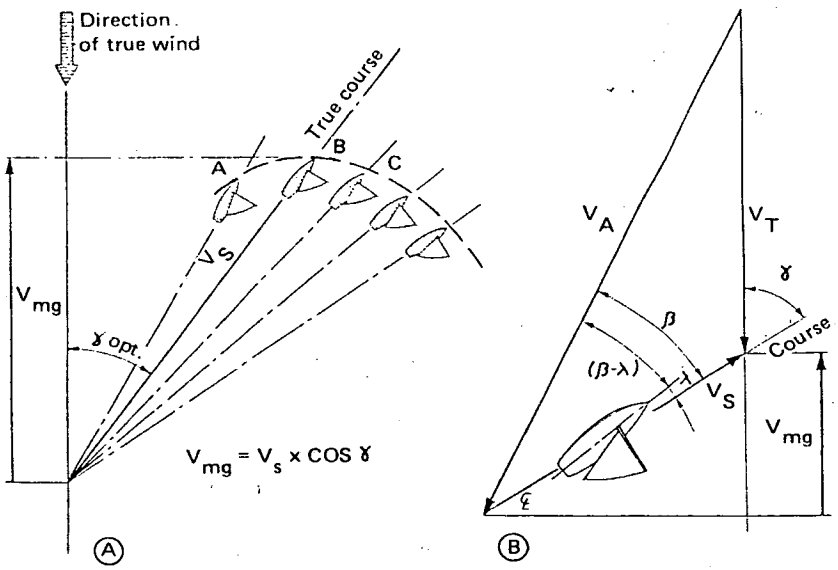
To focus the speed performance prediction results and assist an overall assessment to be made in relation to Figures 12 and 13, we selected three representative points of sailing for closer examination:

- Speed made good to windward (V_{mg}) (see Figure 14);
- Speed when reaching normal to the true wind (γ = 90 degrees)
- Maximum speed before the wind; generally at γ = 80 degrees but in some cases tacking down wind gives a higher speed towards a destination lying directly down wind; in such cases γ < 180 degrees.

Figure 15(a) and (b) presents these comparative speed results for the two selected hulls. As expected, the canoe hull with its much lower displacement/length ratio is consistently faster, but otherwise the relative rankings of the rigs are virtually identical on either of the hulls.

Figure 14

Speed Made Good to Windward



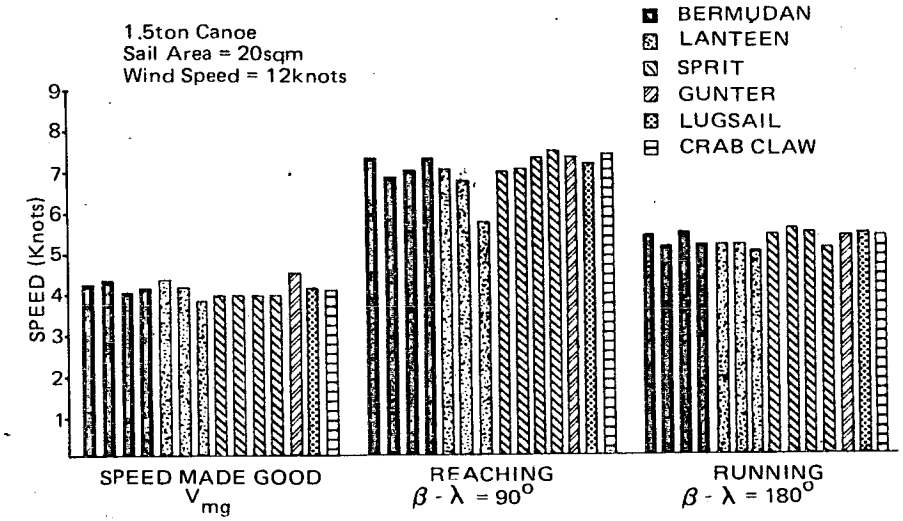
The definition of Vmg is explained in the diagrams, and may be calculated as follows:

$$V_{mg} = V_s \cos \gamma$$

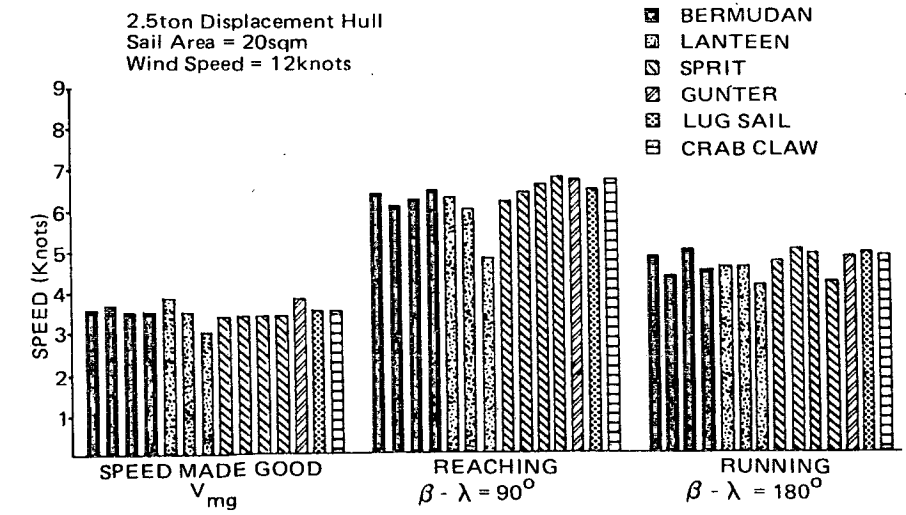
$$\frac{V_{mg}}{V_T} = \frac{\cot \gamma}{\cot(\gamma\ \beta) - \cot \gamma}$$

Figure 15

Comparison of Sailing Speed



Comparison of Sailing Speed



Predicted speed results of the tested rigs mounted on imaginary canoe and displacement hulls.

The distribution of the driving force coefficient (C_x) given in Figure 13 generally reflects the differences in sailing speeds. There are, however, some deviations evident in the case of close hauled headings if the sail criteria in Table 1 are not satisfied. An increase in C_x of a given rig is associated with such a large increase in C_y, such that its C_y/C_x ratio is much higher than that relevant to other comparative rigs.

With the wind tunnel results in mind, the rather unexpected feature of the results presented in Figure 15 is that the crab claw rig tested so far does not stand out as superior to the others. It is undoubtedly a good performer and at heading angles between 110 degrees and 150 degrees is the fastest of all the rigs (Figure 16).

As indicated by the wind tunnel tests, no rig is constantly superior for the whole range of heading angles. There are, however, some consistently poor rigs such as the lanteen rig (iii), regardless of heading angle. Also, there are certainly better rigs than the Bermudan, and this includes on windward courses, where this rig is widely believed to be outstanding. By making predictions of sailing performance on the basis of wind tunnel tests, practical differences between rigs have been demonstrated in qualitative and quantitative terms.

Due to the geometry of actual sailing, and the character of the resistance curves (which take a sharp upturn towards rapidly increasing resistance when the speed/length ratio approaches 1.0), these differences tend to be less in terms of speed than otherwise might be expected from an inspection of driving force component (Cx) alone (Marchaj, 1982). These differences will be larger in light winds, when the hull operates in the friction-resistance regime, and less pronounced in stronger winds when the hull operates in the wave-making regime.

CONCLUSIONS

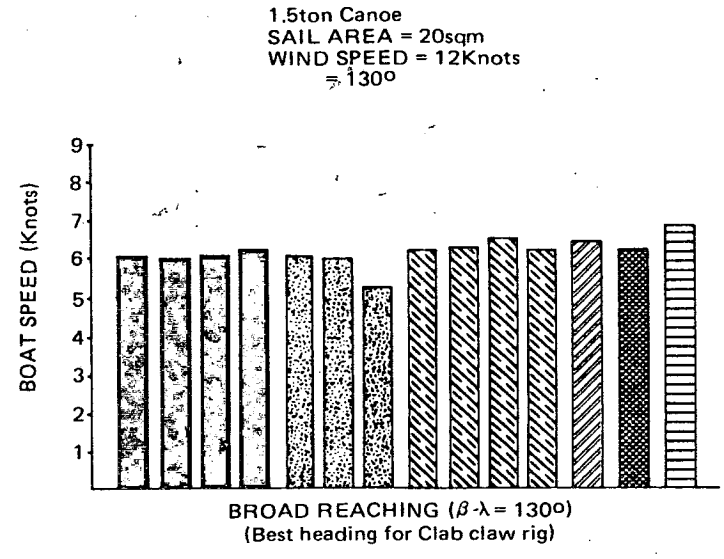
The following conclusions may be reached, either from previous test work and established data or as a direct result of original research conducted during these investigations (and noted as such).

(a) The ratio of mast diameter to mean chord of a mainsail is important when considering the significance of aspect ratio (original work);

(b) Circular section spars are best for working boats (established data);

Figure 16

Comparison of Sailing Speed



Speed comparisons of all sailplans tested, when broad reaching on a canoe hull.

(c) In considering the different sailplans, no single rig emerged as superior for the whole range of heading angles. The tests did, however, show that some were consistently poor, for example, lanteen(iii) (original work);

(d) The Bermudan sailplan is by no means the optimum shape for all-round efficiency which it has long been thought to be (original work). This inefficiency is largely due to uneven sail incidence angles, which cause the head of the sail to stall prematurely, thus causing increased drag (which is aggravated if there is marked sweepback). In addition, airflow breaks down over the same area, because there is high loading. These tests have shown that it is possible to dispense with a significant portion of the head of a Bermudan sail without losing too much thrust (Marchaj, 1979). A rectangular or trapezoidal shape, being near to the known efficiency of an ellipse, would be a better shape (Marchaj, 1979);

(e) Of the three lanteen rigs tested, lanteen rig (i) with the highest aspect ratio (yard most nearly vertical), was the most efficient, being roughly comparable with the best of the Bermudan combinations. Lanteen rig (iii), with the lowest aspect ratio (yard most nearly horizontal), was the worst of all the sails tested, such that its results were double checked for error (original work);

(f) The gunter rig showed particularly well in the close-hauled condition. The sail is, indeed, not unlike the Bermudan sail with the top 15 per cent removed. See conclusion (d) above, which helps to explain this result (original work; Annex, Figures (II) and (VI);

(g) The results of the crab claw sail were, perhaps, one of the highlights of the test program. It was twice as powerful as the admittedly poor lanteen rig (iii), but was also 25 per cent better than most of the other rigs, being particularly efficient off the wind (original work). Further research is indicated;

(h) In the quest for greater boat speed, both sails and hull are interdependent, and neither is more important than the other (Marchaj, 1979, 1982). It is more rewarding to try to improve the aspect which is least efficient and, since artisanal craft are often poorly designed, scope for speed improvement is good;

(i) Improvement in keel design will often have a bigger effect on efficiency to windward than improvement in sails (Marchaj, 1982);

(j) A sail which is twisted more than 10 degrees is inefficient. Where excessive twist (up to 70 degrees) exists, 50 per cent more power can be achieved by efficient use of a vang, if camber is unaffected;

(k) There is little or no driving force coefficient to be gained from increasing sail camber beyond 1/10. Any boat has a maximum tolerable heeling force coefficient. When the total wind force causes this to be reached for a given sail, reduction in camber will reduce drag and thereby, heeling force. Thus, rig and sails need to be flexible so that camber may be controlled independently. This argues for a shape which can be controlled by the crew, which in turn argues for an awareness by the crew of the desirability of such control;

(l) Porous sailcloth allows pressure to equalize on either side of a sail, thereby reducing lift (Marchaj, 1982).

ANNEX

A set of comparative speed performance curves, redrawn from the computer output, is presented in Annex Figures (I) to (VI). They are relevant to the heavier, displacement type of hull. A single true wind speed of 12 knots was selected for comparative purposes. The sailing performance curves are plotted in polar and linear form against V_T. To avoid confusion, no more than three results are superimposed.

Since these figures are more or less self explanatory, they need not be discussed individually. Attention should perhaps be drawn to Figure (VI), in which the crab claw rig performance is presented. As shown earlier (Figure 11), an exceptionally large driving component (Cx) for this rig is generated in broad reaching conditions. Therefore, tacking down wind is required to take full advantage of the crab claw rig when seeking a destination directly down wind in the shortest time (Marchaj, 1979). This can readily be seen from the polar performance plot.

It is important to bear in mind the speed performance curves, Annex Figures (I) to (VI), when making choices between different rigs for different localities. Local wind strengths and the relationship between prevailing wind directions and the courses to and from fishing grounds, for example, must be taken into account.

Figure I

Variation of Sailing Speed with True Wind Angle

Bermudan Rig

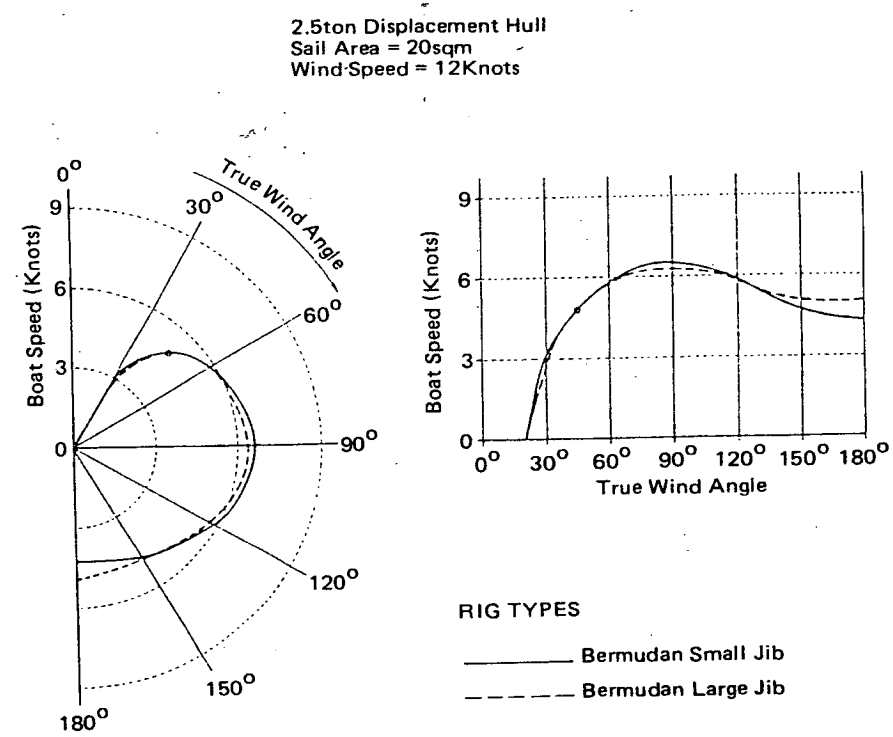


Figure II

Variation of Sailing Speed with True Wind Angle
Bermudan Rig Without Jib

2.5ton Displacement Hull
Sail Area = 20 sqm
Wind Speed = 12Knots

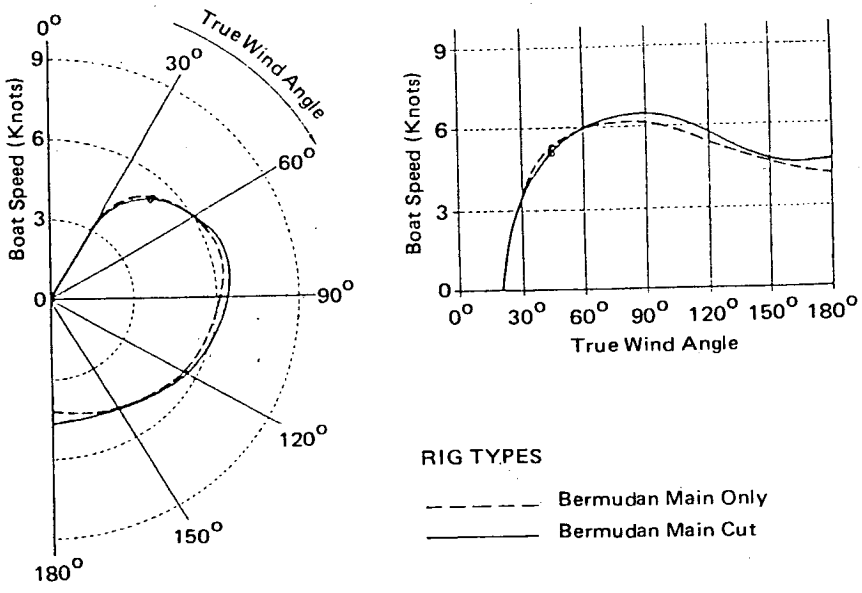


Figure III

Variation of Sailing Speed with True Wind Angle
Lanteen Rigs 1, 2, and 3

2.5ton Displacement Hull
Sail Area = 20sqm
Wind Speed = 12Knots

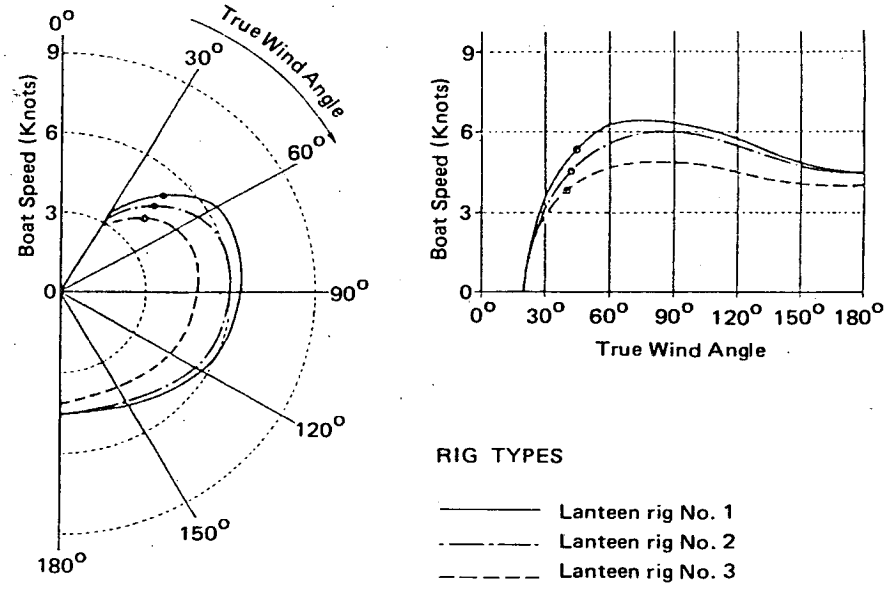


Figure IV

Variation of Sailing Speed with True Wind Angle

Sprit Rigs (i), (ii), and (iii)

2.5ton Displacement Hull
Sail Area = 20sqm
Wind Speed = 12Knots

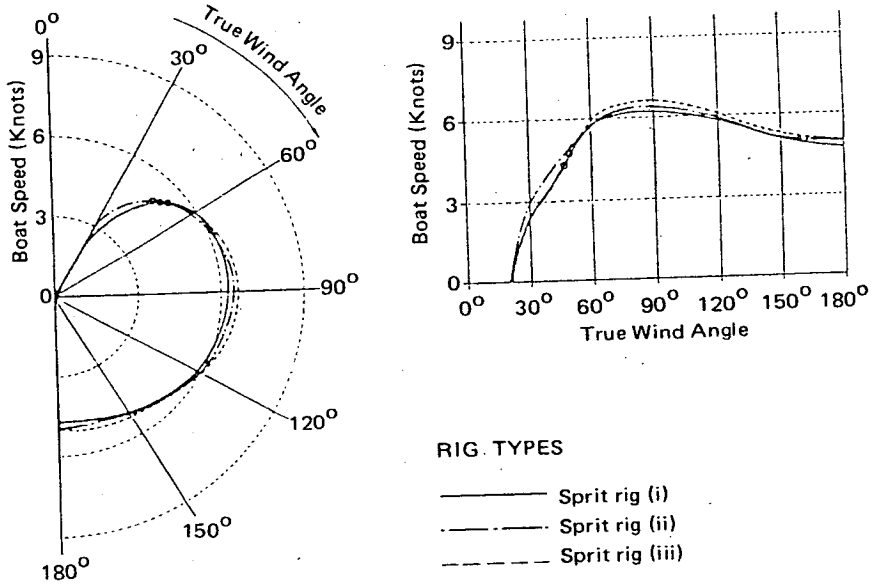


Figure V

Variation of Sailing Speed with True Wind Angle

Sprit Sail with Jib

2.5ton Displacement Hull
Sail Area = 20sqm
Wind Speed = 12Knots

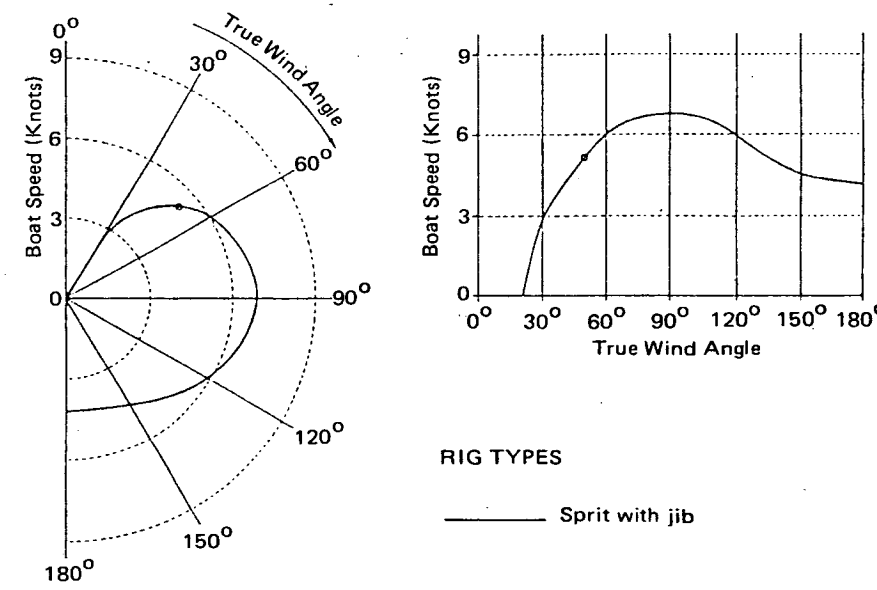
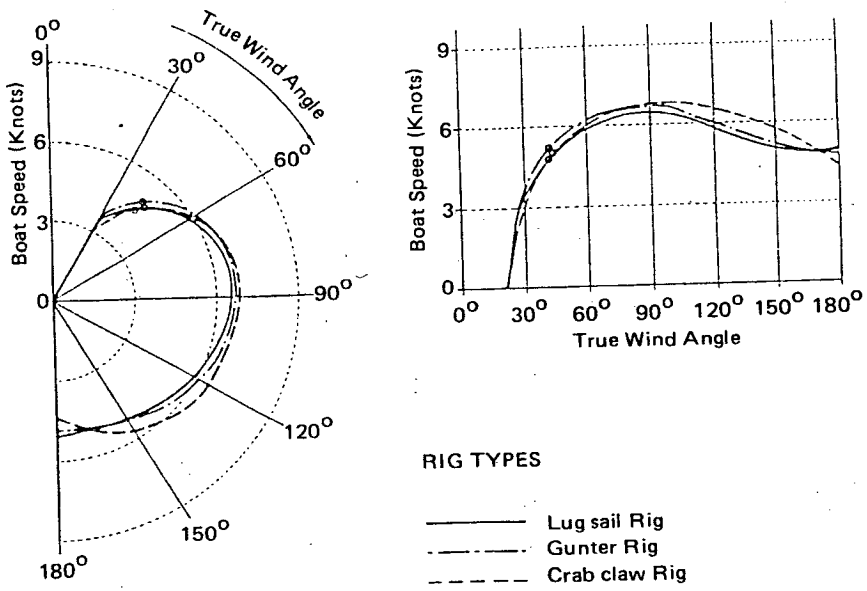


Figure VI

Variation of Sailing Speed with True Wind Angle

Variation for Lugsail, Gunter and Crab Claw

2.5ton Displacement Hull
Sail Area = 20sqm
Wind Speed = 12knots



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4. Marchaj, C. A., "Sailing Theory and Practice", 2nd Edition, Adlard Coles Ltd., London. Dodd, Head & Co., New York.

QUESTIONS AND ANSWERS

Q: Do you see any limitations on the size of the vessels that could use the crab claw rig? (Mr. D. Silk)

A: I cannot say so definitely, but there should not be any limits. If it is a single sail there would be a maximum area, but there is no reason why the crab claw should be considered differently from any other rig.

Q: Can you tell us about the relationship of sail and hull? What kind of sail would be manufactured for commercial craft? (Mr. A. B. Thakur)

A: Both sail and hull contribute to sail performance. If the ratio of the side force generated by the hull and its appendages to hull resistance is higher, the hull is more efficient if driven by sail. If sail is auxiliary, then the ratio is less important. The sail-motor concept is different from pure sail vessels.

Q: I would like to congratulate you on your tunnel experiments. I would like to comment that the side force in the driving force coefficient is important, which may explain why the crab claw was found to be only marginally superior. (Dr. J. Mays)

A: I agree with your observation.

Q: Could you please provide a comprehensive list of factors to be considered (in order of priority) when determining the upper and lower limits of height of (a) conventional sail, (b) Turbosail. (Mr. A. Wajeeh)

A: In broad terms, the primary objective in selecting the rig (its type, planform, height, aspect ratio), is to secure the largest possible driving force from a given area. It must be stressed that of only slightly less importance is the reduction in the heeling force which should be kept as small as possible in order to minimize the leeway angle (and associated induced drag), and the heeling angle which also incurs drag penalty.

Heeling force can be regarded as a penalty one has to accept in order to produce driving force. This applies to almost all types of rigs, Turbosail included. The magnitude of heeling force largely determines what is called 'power to carry sails effectively' which, in turn, is related to the transverse stability of the hull and height of the rig.

Expressing this in a different way, stability of a sailing vessel can be assessed by a ratio known as 'the power to carry sails.' The question to be answered is how the height of the rig affects this ratio. Figure Q-A.1 explains the derivation of the formula in which the height of rig is one of the parameters.

A boat sailing to windward at given apparent wind (V_A) will reach angle of heel (Θ) when the heeling moment:

$$M_H = S_A \times C_H \times q \times h$$

becomes equal to the righting moment:

$$M_R = \Delta \times GM \times \sin \Theta$$

where:

S_A = sail area in square feet

C_H = heeling force coefficient ranging from 1.2 to 1.8 depending on the type of rig and the course sailed to the wind

q = dynamic pressure ($q = 0.00119\ V_A^2$ lb/sq ft)

Δ = displacement in pounds

GM = metacentric height in feet

h = distance between the Center of Effort of the rig (CE) and the Center of Lateral Resistance (CLR). Note that h depends on the height of the rig and shape of the hull.

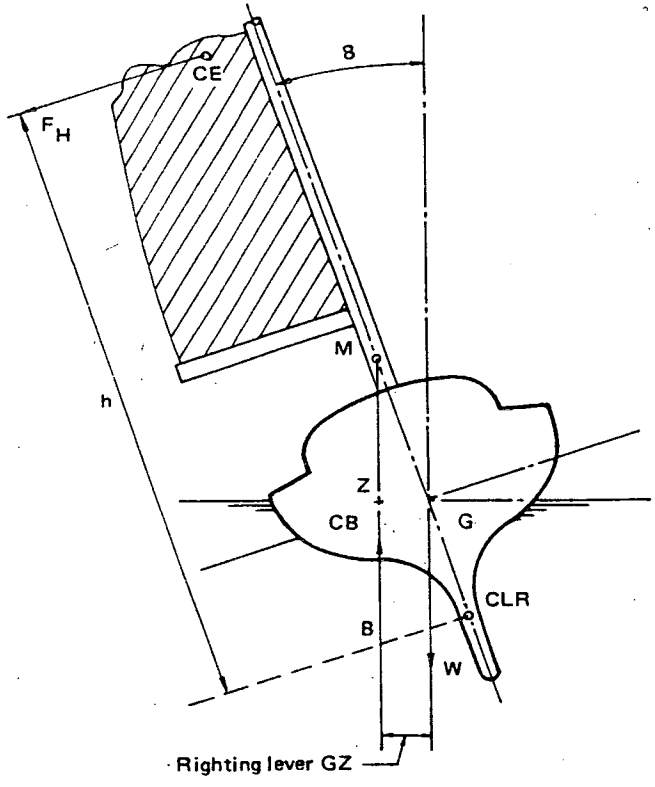
By equating the heeling moment (M_H) to the righting moment (M_R) we find that:

$$\sin \Theta = \frac{S_A \times C_H \times q \times h}{GM}$$

Although this equation is strictly valid on condition that Θ does not exceed about seven degrees, it demonstrates that the height of the rig (related to h in the formula) directly determines the angle of heel and hence the hydrodynamic drag penalty due to heeled hull as well as reduction in the driving force also due to heel. It should be remembered

Figure Q-A-1

Derivation of Formula for Stability Assessment of Sailing Vessel



that, up to about 20 degrees of heel, the driving force is not much affected but, beyond 20 to 25 degrees, its magnitude diminishes at an increasing rate. It can also be seen from the formula that there is a number of other factors such as displacement ($\triangle$), GM, C_H, etc. which control the available driving power a given rig can deliver and which depend both on the shape and efficiency of the hull and rig. These are discussed at length in the author's book *Aero-Hydrodynamics of Sailing,* 1979 (see References).

The Development in Japan of Modern Sail-Assisted Ships for Energy Conservation

Noboru Hamada*

INTRODUCTION

The oil shocks of the 1970s, with their attendant steep rises in the price of bunker oil, spurred a series of developments in marine energy conservation technology. These included improvements in main engine fuel consumption, the development of engines capable of running on cheap, low-grade oil and the development of shaft generators, exhaust gas-driven turbo generator plants, new hull designs, high propulsive efficiency propellers, fins and ducts and new paint materials.

At about this time, the Japan Marine Machinery Development Association (JAMDA) began to investigate the feasibility of operating ships using a form of energy far cheaper than oil, namely, wind power. At this time, work was also in progress on sail propulsion in Europe and America, but the prevailing tendency at the time was to think in terms of using the sail as the main propulsion method. We felt, however, that this would lead to unacceptably high initial cost increases. Therefore, we turned our attention to a system using the sails to assist the main engine. We also re-examined conventional ship designs from the bottom up, to produce a totally integrated sail-assisted design, incorporating the latest energy saving engines, auxiliaries and other equipment.

We felt that it was not enough to simply produce an efficient sail, but that we would also need to produce a total ship system which would complement the sail's performance and which would be commercially viable from the start. It was this radically different design approach which enabled

* President, Japan Marine Machinery Development Association (JAMDA). Dr. Hamada was responsible for designing and developing the sail-assisted system for *Shin Aitoku Maru* and subsequent vessels.

Using the sails to assist the main engine allowed us to produce ships that would be capable, unlike traditional sailing ships, of maintaining tight sailing schedules and which were also extremely stable and capable of maintaining their course with a high degree of accuracy. In terms of sail design, too, the employment of wind theory, tank tests and stability checks in a wind tunnel, enabled us to produce a rigid-framed airfoil sail which needed no extra crew to control it. This, coupled with other innovations in the overall design, led to the construction of a very successful series of ships since 1975, as chronologically set out in Table 1.

TECHNOLOGICAL DEVELOPMENTS BY JAMDA FOR SAIL-ASSISTED SHIPS

The Sails

The choice of sail design was made first of all by carrying out wind tunnel tests on various designs, from which a vertical rigid-framed airfoil sail proved, after sea trials, to be the best design.

The *Shin Aitoku Maru* (see Plate 1) uses two sails, each 12.15 meters high and 8 meters wide. Furling and unfurling are accomplished by means of a hydraulic motor and cylinder system, and the trim angle of the sails is controlled automatically by a computer which adjusts the sails in accordance with wind speed and direction data obtained at five-minute intervals. The sails are automatically furled in winds with an average apparent speed of over 20 meters/second.

These rigid-framed airfoil sails are efficient at using winds from the bow, and propulsive power can be gained from all winds except those from 20 degrees either side of the bow. In other words, a total of 320 degrees of wind direction can be used for propulsion. On the *Usuki Pioneer,* refinements in the sail design have enabled head wind performance to be improved still further so that all winds except those from the 15 degrees on either side of the bow can be used for propulsion. The sails are constructed from steel and polyester, with steel used for the frame, and polyester coated with a special vinyl chloride covering used for the sailcloth. This coating increases the life of the sailcloth, prevents the buildup of dirt, and makes the material fire-resistant.

The *Aitoku Maru* uses a single sail, the area of which is the same as one of the *Shin Aitoku Maru* sails. As a refinement, however, the sail was fitted with slats along its left and right hand sides. However, the benefits gained from these slats proved to be not worth the cost of fitting them, demonstrating very clearly that wind-tunnel test results often do not equate with actual performance at sea.

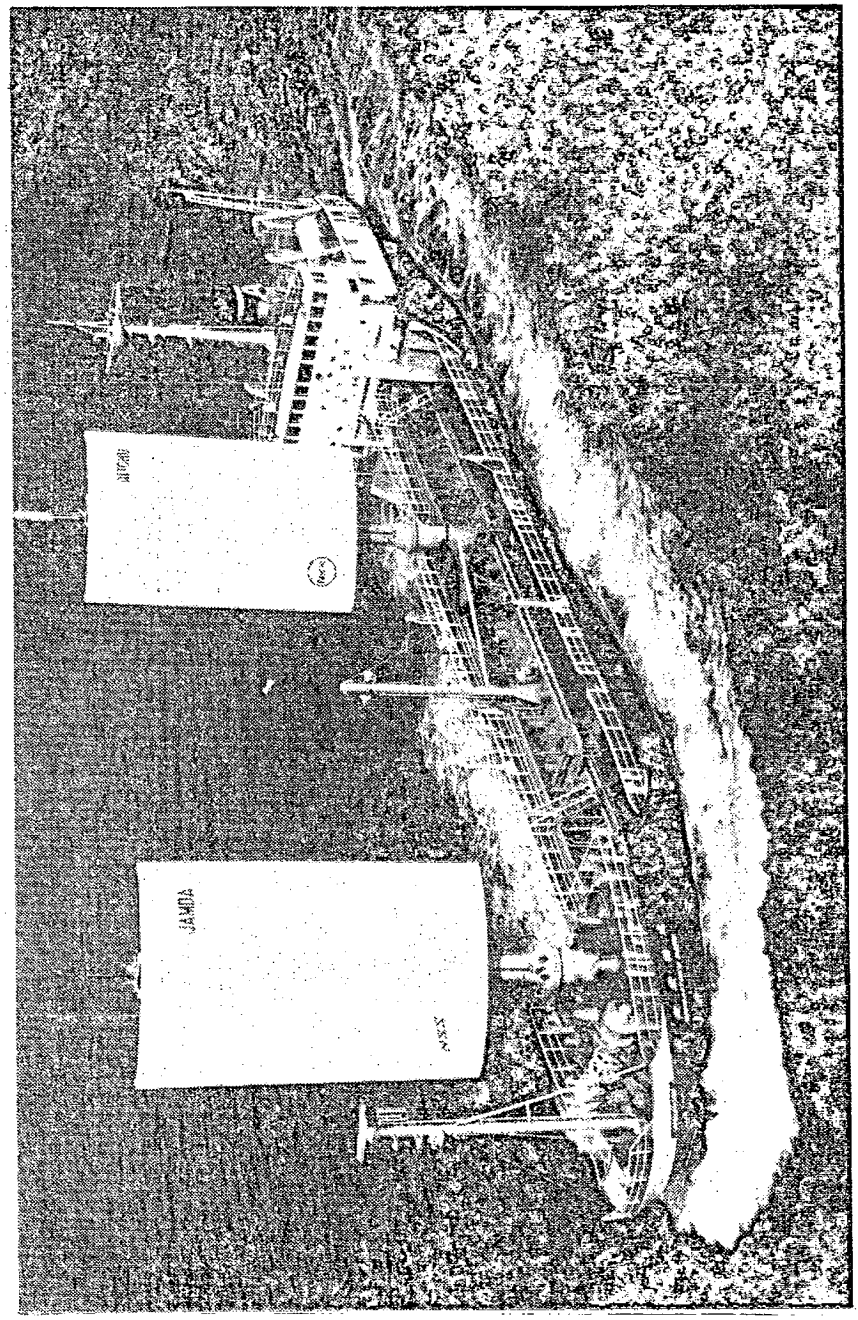
Table 1
List of Completed Modern Wing Sail-Assisted Merchant Vessels

	Date of Completion	Ship's Name	Owner	Planner	Type of Ship	DWT	L x B x d(m)	No. of Sails	Total Sail Area (sq m)	Builder
Small Vessels										
1	Aug. 1980	Shin Aitoku Maru	Aitoku Shipping Company	JAMDA, NKK	Tanker	1600	66x10.6x4.76	2	200	Imamura Shipbuilding Company
2	Apr. 1982	Aitoku Maru	Aitoku Shipping Company	JAMDA	Tanker	1680	66x10.6x4.76	1	85	Imamura Shipbuilding Company
3	Jun. 1983	Nittoku Maru	Aitoku Shipping Company	JAMDA	Chemical tanker	633	52x10x3.6	1	96	Imamura Shipbuilding Company
4	Apr. 1983	Senyo Maru	Fuyo Kaiun k.k.	NKK	Bulk carrier	2081	72x12.6x4.72	2	233	Narasaki Shipbuilding Company
5	May 1983	Nissan Maru	Nissan Senpaku k.k.	NKK	Bulk carrier	2098	72x12.6x4.72	2	233	Sasaki Zosen k.k.
6	May 1984	Daiichi Kyoei Maru	Kobe Senpaku Kaisha Ltd.	JAMDA, STK	Tanker	4894	95.8x15x7.8	1	216	Higaki Shipbuilding
7	Oct. 1984	Calbee Potato Maru	Yachiyo Senpaku	JAMDA, STK	Bulk carrier	1480	71.0x13.0x3.6	1	96	Miura Zosen
8	Feb. 1985	Hanyou Maru	Kokka Sangyo	JAMDA, STK	Tanker	1250	60.0x10.2x4.1	1	96	Kyoei Zosen
9	Feb. 1985	Hokushin Maru	Shinsei Kaiun	JAMDA, STK	Chemical tanker	390	43.5x8.4x3.25	1	54	Teraoka Shipyard
10	Aug. 1985	Shinko Maru	Seibu Tanker	JAMDA, STK	Chemical tanker	3150	77.0x14.0x5.6	1	150	Kanmon Shipbuilding
11	Nov. 1985	Yamakuni Maru	Houwa kaiun	JAMDA, STK	Bulk carrier	6500	99.95x17.5x7.1	1*	220	Honda Shipbuilding
12	Feb. 1986		Yachiyo Gyogyo	JAMDA, STK	Tuna long liner	G/T319	44.0x8.5x3.22	2	96	Katsuura Dock
13	1986			JAMDA, STK	Bulk carrier	8000				
14	1986			JAMDA, STK	Bulk carrier	6500	95x18x7	1*	220	
Large Vessels										
1	Nov. 1984	Usuki Pioneer	Tanaka Industries Ltd.	JAMDA, STK	Bulk carrier	26000	152x25.2x10.57	2	640	Usuki Iron Works Ltd.
2	Planning			NKK	Bulk carrier	34550	167x29.5x10.5	6	2600	
3	Planning			W. Germany	Bulk carrier	12000	160x22x10	5	8000	
4	Planning			Belgium	Bulk carrier	30000	167.5x27x10	5	12160	
5	Planning			USSR	Bulk carrier	50000		7	14000	
6	Planning			USA	Bulk carrier	28000	156x24.4x9.7	5	2680	

* Combined derrick post and sail post

Source: Japan Marine Machinery Development Association, 1 November 1985.

Plate 1



Shin Aitoku Maru

On the *Nittoku Maru,* the central panel in front of the mast was dispensed with, allowing the sail to be furled completely parallel, thereby reducing wind resistance. In addition, in order to keep the sail unfurled in as high a wind speed as possible, thereby maximizing stability benefits, we divided the sail into upper and lower sections capable of being independently furled and unfurled. The upper section is furled in average apparent wind speeds over 20 meters per second, with the lower section furled at 25 meters per second. We also incorporated into the *Nittoku Maru* a collapsible mast in order to reduce her air-draft when passing under low bridges.

The *Usuki Pioneer* (see Plate 2) employs the same type of vertically divided, parallel furling rigid framed sails as the *Nittoku Maru.* However, to meet the requirement for a maximum air-draft of 40 meters, the height of the sails was limited to 16 meters, with a width of 20 meters, giving an aspect ratio of 0.8.

With the exception of the *Usuki Pioneer,* all the sail-assisted ships built since the *Nittoku Maru* use single sails of the vertically divided, parallel furling type. However, the sail-assisted tuna long-liner, at present under construction, will be fitted with two sails to allow the use of the sails as a dynamic positioning system.

The Hull

On the *Shin Aitoku Maru,* a slim hull design with a revised bow was employed in order to reduce hull drag. The stern was also redesigned to accommodate the large diameter propeller used. In addition, the rudder was made larger than the norm for this type of ship, and the height of the bridge was reduced by one level in order to reduce wind resistance.

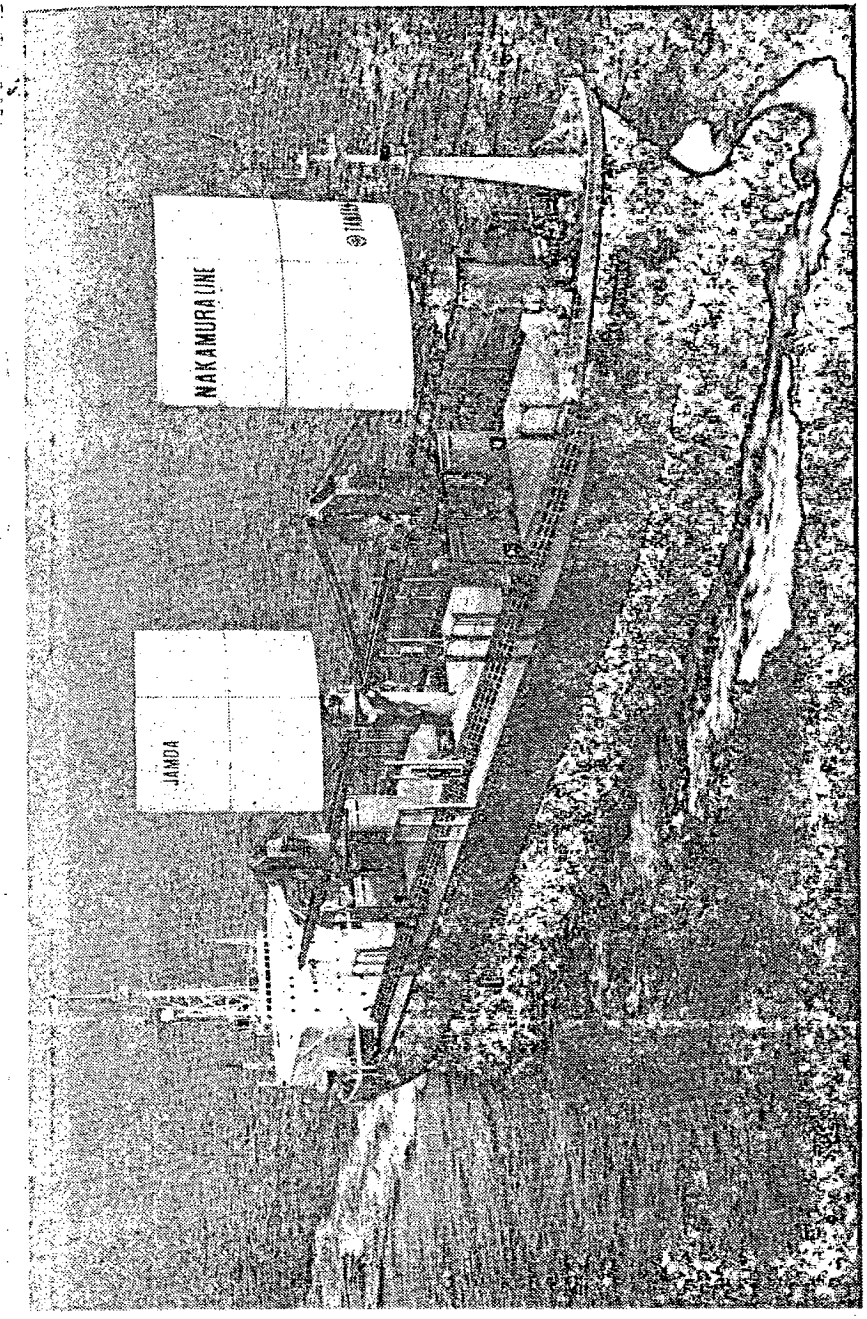
To check if this hull design was adequately stable when the sails were fitted, we carried out careful testing in a wind-tunnel tank, and it was ascertained that stability was equal to that of passenger ships, with a 'C' coefficient in excess of 1.0.

On the *Usuki Pioneer,* the frontal area of the bridge was made narrower, and the corners were rounded so as to reduce wind resistance.

The Propulsion System

The secret of the success of the motor-driven sail-assisted concept lies in the propulsion system used. When power is gained from the sails, the engine output is automatically reduced, while a constant sailing speed is maintained. The *Shin Aitoku Maru* uses a 1600 hp (250 rpm) low-speed, four-cycle engine driving a large diameter low-speed propeller. The system

Plate 2



Usuki Pioneer

is capable of burning 'C' grade heavy oil down to loads as low as 40 per cent of maximum continuous rating (MCR). A further feature of the system is that fuel consumption does not worsen even at low loads. This means that power gained from the sails can be utilized to the maximum benefit (see Figure 1).

This propulsion system underwent further refinement in the *Usuki Pioneer,* which uses a twin-engine single-shaft configuration allowing output to be reduced to 20 per cent of MCR while still burning grade 'C' oil. This allowed us to make even greater use of the power gained from the sails (see Figure 2). Control of the engines and propeller pitch is carried out entirely by the computer.

Other Components

JAMDA's sail-assisted ships employ homogenisers which grind and crush sludge, pass it through a fine-mesh filter to remove metallic impurities and then incorporate it into the fuel to be burnt. In spite of the use of sludge fuel, however, no ill-effects were found, and wear on the cylinder liners and the piston rings is no more than in a conventional type of system. Use of the homogeniser also has the added advantage of not having to spend time on the disposal of sludge.

The ships employ exhaust gas economizers which exchange heat to air and thence to oil, with the oil used as the heating medium. This system prevents the occurrence of corrosion from exhaust gas and has a high heat output, allowing not only crew quarters heating to be provided, but also having sufficient capacity to heat fuel and lubrication oil. The use of oil as the heating medium ensures a high level of efficiency, and dispenses with the need to carry a water tank for steam preheating.

In addition to the sail control and computers for propulsion system control, modern sail-assisted ships also use computers for navigational manual work and for stability confirmation.

FUTURE PLANS IN JAPAN

As of August 1985, ten coastal and one foreign-going modern sail-assisted ships were in service, with another two vessels scheduled for completion within the year. One of these new vessels will be a sail-assisted tuna long liner, and if results from this ship are favorable, further sail-assisted fishing vessels may be built.

As yet, only one foreign-going sail-assisted ship is in service, but when one considers that in 1984 the six biggest shipping companies in Japan used

Figure 1

Engine Output Control

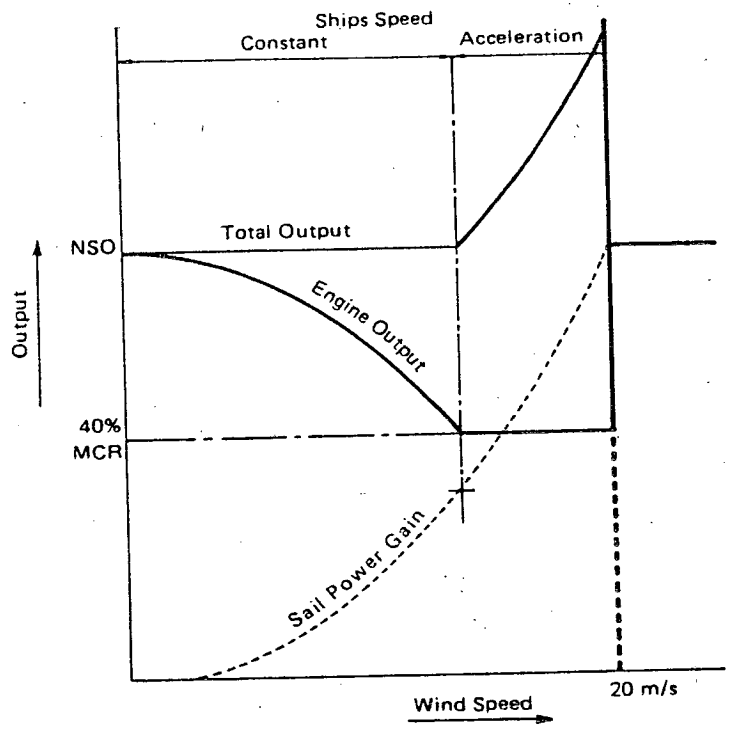
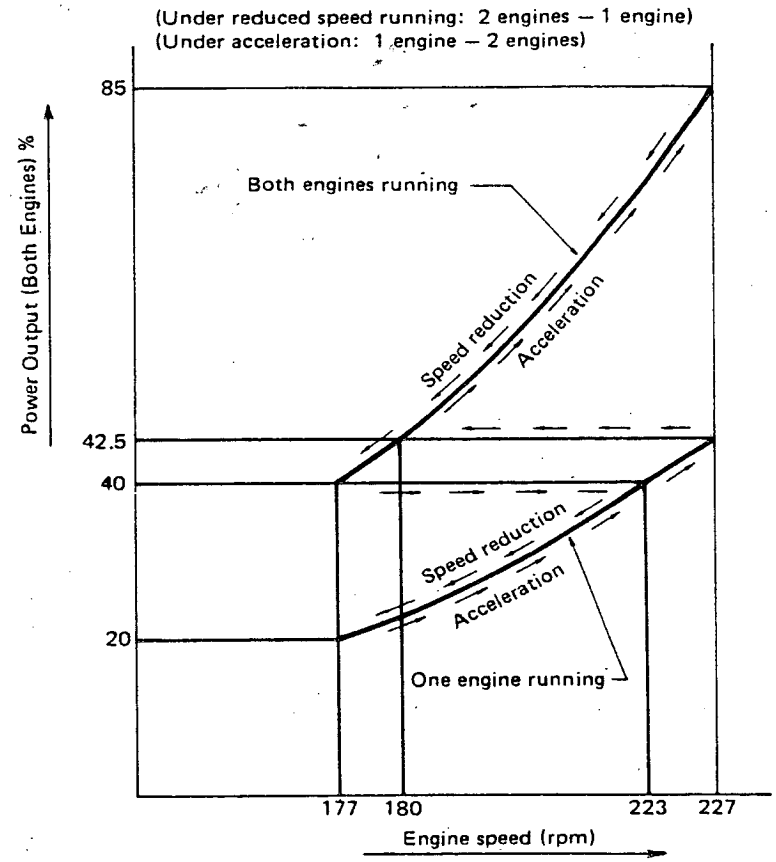


Figure 2

No. 1/No. 2 Engine Auto Switchover System



Note: This graph shows a simplified version of the program employed. The actual program offers a considerable number of variations.

eight million tons of bunker oil at a total cost of 358.6 billion yen, it is obvious that there is a great potential benefit. Last year, fuel costs accounted for 40 per cent of total shipping costs in Japan. Thus, if even only 10 per cent of this could be saved by using sail-assistance, that would mean savings of 800,000 tons and 36 billion yen, an appreciable sum.

To this end, we are proceeding to the design of larger ocean-going vessels, including a 60,000 ton bulker and an 80,000 ton tanker, both of which are at present undergoing wind-tunnel tank tests. In addition to this, we are working on the use of new materials (aluminum and stainless steel) for the sails in order to facilitate volume production at lower cost. Improvements are also being made in the design and performance of the sails and the low load and fuel consumption characteristics of the main engines, with work planned on improvements in auxiliary machinery.

REGIONAL USES IN COASTAL AND INTERISLAND TRADE

The question of whether sail-assisted motor ships are suited to coastal and interisland trades in Asia and the Pacific is one that can only be answered by actually building a ship for that purpose and using it. Data from actual ships are worth more than any number of theoretical test figures, and building a ship of this type as quickly as possible would speed development greatly.

We have designed small scale sail-assisted ships, the smallest (under construction) being only 299 gross registered tons, but work will have to be done to ascertain the most suitable hull design for any particular coastal or interisland trade, with attention paid to water depth, harbor facilities, etc. Careful calculations of sail cost against fuel saving would also have to be made, with other benefits, such as improved maintenance of schedules, improved stability taken into account. We feel, however, that if sufficient care is taken at the planning stage, sail-assisted ships could play a valuable role in the Asian and Pacific trades.

QUESTIONS AND ANSWERS

Q: Is there an opportunity to reduce installed engine power when the vessel has sails? (Dr. C. J. Satchwell)

A: Yes, there is. For instance, in the case of *Shin Aitoku Maru,* the next ship can use 1,200 hp instead of 1,600 hp. However, shipowners usually want more than horsepower to get better value out of the relatively fixed costs of the vessel and crew.

Q: I noticed that from the 11 vessels that you have in service, all are tankers or bulk carriers except for the tuna fishing vessel. It seems to me that there is more potential for sail assistance in vessels such as roll-on roll-off ships and car carrier vessels which are loaded horizontally instead of through the deck. I wonder if you would care to comment on that. (Prof. J. King)

A: I have the same view and I would like to make a sail rig for a car carrier and a container ship. However, I cannot find a shipowner to order such a vessel with wind assistance equipment.

Q: I understand that on the premier voyage of *Usuki Pioneer* weather routing was used. Has weather routing continued to be used in the operation of the *Usuki Pioneer* or other ships? If so, what has been the experience? (Dr. J. Mays)

A: They used it on the maiden voyage, and they would like to keep using this system.

Q: You have made no reference to a ship called the *Aqua City* which preceded the *Usuki Pioneer.* It uses the same type of sail, but in a different configuration. That ship is a little larger than *Usuki Pioneer.* (Capt. G. Veres)

A: *Aqua City* is an experimental ship, not a commercial one.

Q: *Aqua City* does trade on a revenue-earning basis. She is another sail-assisted ship in existence. Although the sails are different, the performance record is similar to *Usuki Pioneer's.* (Capt. G. Veres)

A: I agree that *Aqua City* is a good ship, but I have no figures on the relationship between its sail and reduction in the consumption of fuel.

Q: The *Aqua City* was the first Japanese bulk carrier to be equipped with two rigid airfoil type sails controlled by computer, although they were installed in different configuration from the *Usuki Pioneer*. The main engines and the automated sails on the *Aqua City* are controlled by the same computer and the power output of the main engines is automatically reduced corresponding to the propulsive force derived from the sails. (Capt. G. Veres)

A: As I pointed out, the *Aqua City* was not a true modern sail-assisted ship, but rather was intended as a test bed for NKK's twin sail system. It just so happened that NKK was constructing two new vessels anyway and they took the opportunity to fit one with sails. The *Aqua City* was, therefore, a conventional ship fitted with sails, rather than one designed from the start for sail assistance. The sails were in fact removed this March. (The installation was originally funded by NKK, not the vessel's owner).

It should also be noted that the *Aqua City* did not have the sophisticated sail-engine computer links used on the JAMDA ships and could not have achieved reductions in engine load corresponding to power gains from the sails, because its main engine was not suitable for running at very low loads using low grade fuel.

Q: Could you tell us if the savings of US$200,000 to 360,000 is a saving in the overall cost of operation or in the fuel only? And how does that figure break down? In the case of sail, how do you measure the savings from the sail itself? (Mr. J. Constans)

A: Right now, it is too early to make an estimate of how much savings were obtained for each category of operating cost. If sail assistance is provided for existing ships, then cruising speed can be increased and this would lead to more intensive use of the vessel and lower costs per ton-km.

Q: In your film, it was explained that the fuel savings recorded were approximately twice those which were predicted. I wonder if you can give possible explanations for this very large extra benefit. (Mr. C. Palmer)

A: I talked to the shipowners and they confirmed that the savings made were more than they anticipated. It is not a scientific calculation.

Q: You have distributed well-illustrated brochures on the *Shin Aitoku Maru* and the *Usuki Pioneer* but I fail to find some technical details on the wing sail system. In particular, can you indicate, for both ships, the weight above deck of each system, that is, the mast, the sail itself and the associated mechanisms? (Mr. J. Constans)

A: The above-deck weights of the JAMDA sails are:
a) *Shin Aitoku Maru:* foresail 11.5 tons, aft sail 12.5 tons; and
b) *Usuki Pioneer:* each sail 65 tons, total 130 tons.
These figures are for the mast and the sail system.

Q: In developing the *Shin Aitoku Maru* and *Usuki Pioneer*, a number of fuel efficiency features have been incorporated into the designs and the fuel advantages gained from the motor assisted sail only would be most interesting. An indication of the capital cost of the sail installation would also be useful. (Mr. G. Davison)

A: Our aim has been from the start to keep the cost of the sail system below 10 per cent of the cost of the vessel itself. This has been the case with the ships built so far, but we are confident that capital costs can be further reduced by the use of different materials, and by standardization of designs and components. We are aiming at a figure of six to eight per cent of vessel cost.

Q: The *Shin Aitoku Maru* has been compared with an 'ordinary ship' in Table 1 of the JAMDA publication dated September 1983 and claims of about 50 per cent fuel oil saving have been made on the basis of similar vessels and that a large part of the fuel savings claimed could be incorporated into any new design without sail, that is:
a) Adoption of higher L/B ratio reduces the Froude Number and resistance coefficient. One figure indicates a reduction in power requirements of at least 25 per cent;
b) Block coefficient reduced from 0.72 to 0.68 (included in (a) above);
c) More efficient diesel engine (163 vs 143 gr/ps/h, that is, 12 per cent);
d) The use of larger propeller diameter and presumably lower engine revolutions should improve efficiency but this will be reduced by the use of a controlled pitch propeller required for the shaft generator operation; and
e) There are a number of other fuel efficiency features such as shaft generator, heating, etc. which provide a further six per cent saving.

I presume that the saving for self-polishing paint is included in item (a). This would indicate that at least 43 per cent of the savings are available from other design features leaving about 10 per cent attributable to the sails. Could you comment on this? (Mr. G. Davison)

A: With regard to your comments about the comparison between the *Shin Aitoku Maru* and conventional ships, I would agree that it would be more desirable if the comparison could have been made between otherwise identical vessels, but this was not possible, mainly due to sufficient funding not being available to us in Japan to carry out such a comparison.

As you saw in the video, the vessel used for comparison was the *Hoei Maru*. This ship was built two years after the *Shin Aitoku Maru* and was designed as a fuel-efficient ship incorporating energy saving features current at that time.

It should be stressed that JAMDA has never claimed that the published fuel saving figure of about 50 per cent was due to the sails alone. We had in fact been considering the application of the other energy saving techniques you mentioned for some time, but shipowners in our country are very conservative and were not keen on adopting them. We therefore conceived the idea of a total energy saving ship using sail assistance. In order to do this, it was necessary to design new main engines capable of running on low grade fuel at low load, without fuel consumption penalties. This was so that the engines could absorb all the power gain from the sails. We then asked a shipowner to build the vessel as a complete package. From the beginning, therefore, we considered the sail as only one part of the total system.

Having said all that, we were able to get an idea of the degree of saving from the sails alone by comparing results from the *Shin Aitoku Maru* and the *Aitoku Maru,* a sister ship of similar configuration, which was run without sails for the first few months of its life. This comparison indicated that savings due to the sails alone were between 20 to 25 per cent. It is most important, however, that the engine system is capable of absorbing the gains from the sails, and this is why I said that the engines are the secret of the success of the JAMDA system. The contribution of the sails, too, is not just in fuel saving, but also in stability, with reductions in rolling and in yawing.

Q: The cargo oil capacity of *Shin Aitoku Maru* is shown to be only 1,300 cu m compared with 1,600 cu m for an 'ordinary ship'. Has this affected revenues, as she may not be able to load full cargoes of heavy oil with specific gravity greater than 0.81. (Mr. G. Davison)

A: The reduced capacity of *Shin Aitoku Maru* was the result of the fact that the ship was originally designed for use in the international waters near Japan. As the vessel is now operating in domestic waters, it carries the same amount of cargo oil as other comparable ships.

Q: Regarding the claimed 30 per cent reduction in loading/discharge time for the *Usuki Pioneer,* could you advise if the conventional ships were equipped with 25 ton electric cranes, as the modest reduction in engine room length is unlikely to affect the hatch size significantly when spread over four holds and I suspect the improvement comes from other features. (Mr. G. Davison)

A: The claimed reduction in loading/discharge time for the *Usuki Pioneer* was in comparison to a similarly sized and equipped Japanese vessel loading at Tacoma at the same time as the *Usuki Pioneer.* It was felt that the reason for the difference was the *Usuki Pioneer's* four holds and the difference in the length of the holds and hatches. At first, the cargo owners, Weyerhauser Ltd., were worried that the sails might interfere with loading and unloading, but the comparison indicated that the sails did not interfere in any way.

Q: Can existing petroleum tankers be sail retrofitted here in Manila under supervision of a manufacturer/designer? (Mr. S. dela Merced)

A: It should be pointed out that although retrofitting is technically feasible, JAMDA does not usually recommend it. The reason for this is that the JAMDA sail was not designed in isolation, but was from the start intended as part of a total energy-saving ship system.

The problem with retrofitting is that unless the vessel to be used has engines capable of burning 'C' grade heavy oil at loads down to, say, 30 per cent of maximum without fuel consumption penalties, the power gained from the sails cannot effectively be fed back to the engines, and much of the possible saving is lost. This problem was apparent in the *Aqua City* which lacked the special engine and computer systems of the JAMDA ships, and which, despite achieving savings, did not, we feel, realise the full potential of the sails. Our advice would therefore be that, before setting out to retrofit a ship with sails, you should consider carefully whether this will enable you to obtain maximum benefits.

Q: Is the use of soft sails in petroleum tankers acceptable to ship classification societies/finance companies/safety people in the oil industry, considering the volatile nature of the product handled? (Mr. S. dela Merced)

A: Although the JAMDA sail is in essence a rigid sail, a man-made sailcloth is used in places to reduce weight. This cloth is, however, fully treated with a flame resistant coating, and the sail system meets the safety requirements of both JG and NK classification societies.

Q: The use of sail results in reductions in ship motion. What reductions in resistance come from ship motion reduction? (Dr. C. J. Satchwell)

A: In the case of the *Usuki Pioneer* the use of the sail system has resulted in reductions of 20-30 per cent in roll, and 10-18 per cent in yawing. Reductions in ship motion have resulted in an improvement in course-keeping ability which has led to further reductions in fuel consumption. It should perhaps also be pointed out that we have noted improved reliability and longevity in ship machinery as a result of reduced mechanical loading due to the reduction in ship motion.

Q: What reductions can be made in installed engine power by the use of sail? (Dr. C. J. Satchwell)

A: As far as installed engine power is concerned, we have not yet reached a final conclusion about exact reduction figures. In the case of *Usuki Pioneer,* installed engine power was reduced from an originally intended figure of approximately 8,000 hp in the light of the results from other vessels. Since then, actual results from the ship on the north Pacific route have shown that, sailing fully loaded and maintaining a speed of 13.5 knots, half the ship's sailing days per annum have been completed using an average power of 2,890 hp, a quarter at 1,927 hp and the remaining quarter of sailing time at 5,780 hp. This may give you some idea of the levels of power reduction possible.

Preliminary Design Study of Intraisland Transport Vessels for the Ha'apai Group of Islands in the Kingdom of Tonga

Colin Palmer*

INTRODUCTION

A regional development workshop in March 1981, conducted for the Ha'apai group of islands in the Kingdom of Tonga, identified the problem of providing safe, reliable and regular shipping connections within the island group. Recognizing the value of a project to address the problem and its possible application for other Pacific island groups, three United Nations agencies[1] reached an agreement for UNDAT to study the most appropriate design and operation of a Government-owned vessel, to be operated within the Ha'apai group of islands. The resultant study by Messrs. John Eyre and Colin E. Philp was completed in August 1982 (Eyre and Philp, 1982). The Government of Tonga had meanwhile arranged for a survey to ascertain the current and projected movements of people, animals and goods in the Ha'apai area. This survey was carried out by Miss Rosemary Dillon of the Central Planning Department and Mr. Saia Kami of the Statistics Department of the Government of Tonga. The report on this survey also became available in 1982 (Kami and Dillon, 1982).

Subsequently, in June 1983, in consultation with UNDAT, the UN-ESCAP Division for Shipping, Ports and Inland Waterways took over the task of bringing the Project to the implementation stage. Meanwhile, it had since been submitted to several possible donor governments for consideration. It appeared, however, that insufficient insight into the financial and

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1 United Nations Conference on Trade and Development (UNCTAD); United Nations Development Assistance Team (UNDAT); and United Nations Economic and Social Commission for Asia and the Pacific (UN-ESCAP).

technical feasibility of the Project was often cited as the reason for lack of interest to support the Project. Yet, a proper feasibility study could only be undertaken if the necessary funds were made available.

This procedural circle was broken when UN-ESCAP found Gifford and Partners, Consulting Engineers who are involved in the development of wind-power technology, willing to assist by combining the various reports and other relevant data and improving the presentation towards the level of a preliminary feasibility study. With their extensive knowledge of various rig configurations and results of sail propulsion research, Gifford and Partners could further evaluate the potential for application of modern sail technology.

When UN-ESCAP and the Asian Development Bank reached agreement on the inclusion of a feasibility study of an intraisland sailing vessel for Tonga as a discussion topic for the Bank-sponsored Regional Conference on Sail-Motor Propulsion (the Conference), UN-ESCAP requested Gifford and Partners to prepare and present the topic at the Conference. This resultant paper was prepared without the benefit of a visit to the area, but information on transport statistics and costs was available from the above-mentioned work by Eyre and Philp, and Kami and Dillon. Information on environmental conditions was obtained from British Admiralty charts, pilot books and additional weather statistics from the United Kingdom Meteorological Office.

OBJECTIVES AND SCOPE

The objectives and scope of this paper can be grouped under the following headings:

(i) Determination of the existing patterns of demand and an assessment of the potential for expansion;

(ii) Development of specifications for vessels to serve these routes;

(iii) Conceptual design of the vessels;

(iv) Prediction of optimum operating strategies;

(v) Prediction of operating costs;

(vi) Assessment of the effect of variable inputs to economic analysis, with particular reference to fuel costs; and

(vii) Identification of areas for further study.

PATTERN OF DEMAND

The Ha'apai Group

The Ha'apai group is a subgroup of islands within the archipelagic Kingdom of Tonga. The Tongan chain of islands lies some 2,500 km north-east of New Zealand and stretches for approximately 600 km from north to south (see Map 1). Tonga can be conveniently considered as comprising three distinct subgroups of islands: Vavau in the north, Ha'apai in the center and Tongatapu in the south. Strictly speaking, the central Ha'apai group which is the focus of this paper, can be further subdivided into the Kotu and Nomuka groups (see Map 2).

Passenger and Cargo Movements in Ha'apai

With the use of data from Kami and Dillon, the existing pattern of passenger and cargo movements within the islands was studied. Data in Kami and Dillon, obtained from interviews of boat owners, focused on a period of only one month (December 1981) and appeared to rely heavily on the memory of the persons interviewed. However, the data are generally considered to be reasonably reliable with a tendency to be conservative, particularly with respect to cargo movement. Pangai, on the island of Lifuka, was the destination of the majority of cargo and passenger movements, though the data do not show clearly the relative magnitudes of movements in opposite directions (that is, to or from a particular point).

Kami and Dillon expressed the view that for cargo movements, at least, roughly equal quantities are moved to and from Pangai. The trend for passenger movements, on the other hand, is not as clear. However, assuming more or less stable populations, the presence of passenger movements, heavily biased in one direction on a particular route, seems unlikely. Consequently, the following analysis assumes that the movements on each route are also roughly equal in each direction. Further, it is assumed that where passengers and cargo are carried, the relative proportions of each are also roughly equal in each direction. In view of the generalized approach adopted in later sections of this paper, the validity of these assumptions will, however, have little impact on the conclusions. If at a later stage the study is refined, more information on the directions of passenger and cargo movements will be required.

On the basis of data in Kami and Dillon, illustrations were prepared to form a picture of the demand. Figure 1(a) shows the magnitude of monthly passenger movements on the 18 intraisland routes which were studied. It indicates that they fall into three distinct groups:

Group 1: Two high volume routes;

Group 2: Three medium volume routes; and

Group 3: Thirteen low volume routes.

Although it is not shown in Figure 1(a), there is also a tendency for the higher volume routes to be of short distance. Figure 1(b) presents a similar picture for cargo movements. In this case there are not such clear-cut groupings, but the overall pattern is similar to that for the passenger movements. With regard to vessel design, the relative magnitudes of cargo and passenger movements on the routes are of interest. Figure 2(a) shows both cargo and passenger movements on the five routes of groups 1 and 2 of Figure 1(a). Figure 2(b) shows the ratio of passengers to cargo on these primary routes. With one exception, the ratio is remarkably constant at approximately seven passengers per ton of cargo. The exception is the Ha'ano-Lifuka route, which appears to be primarily a passenger route.

On the secondary routes the correlation is much less well defined, as shown in Figure 2(c). Although it is difficult to generalize from this illustration, it could be concluded that most of the secondary routes involve passenger movements of 40 to 50 persons per month and between two and five tons of cargo.

Finally, the geographic distribution of these routes is shown in Figure 3. Figure 3(a) shows the primary routes and Figure 3(b), the secondary routes. They indicate close correlation between passenger and cargo movements on the primary routes as well as the relatively short distances involved. In contrast, the secondary routes tend to be longer and less correlated.

Future Demand and Expansion

The provision of additional intraisland services is to be directed not only towards existing demand but also towards the opening up of new routes and expanding the economy of the Ha'apai group.

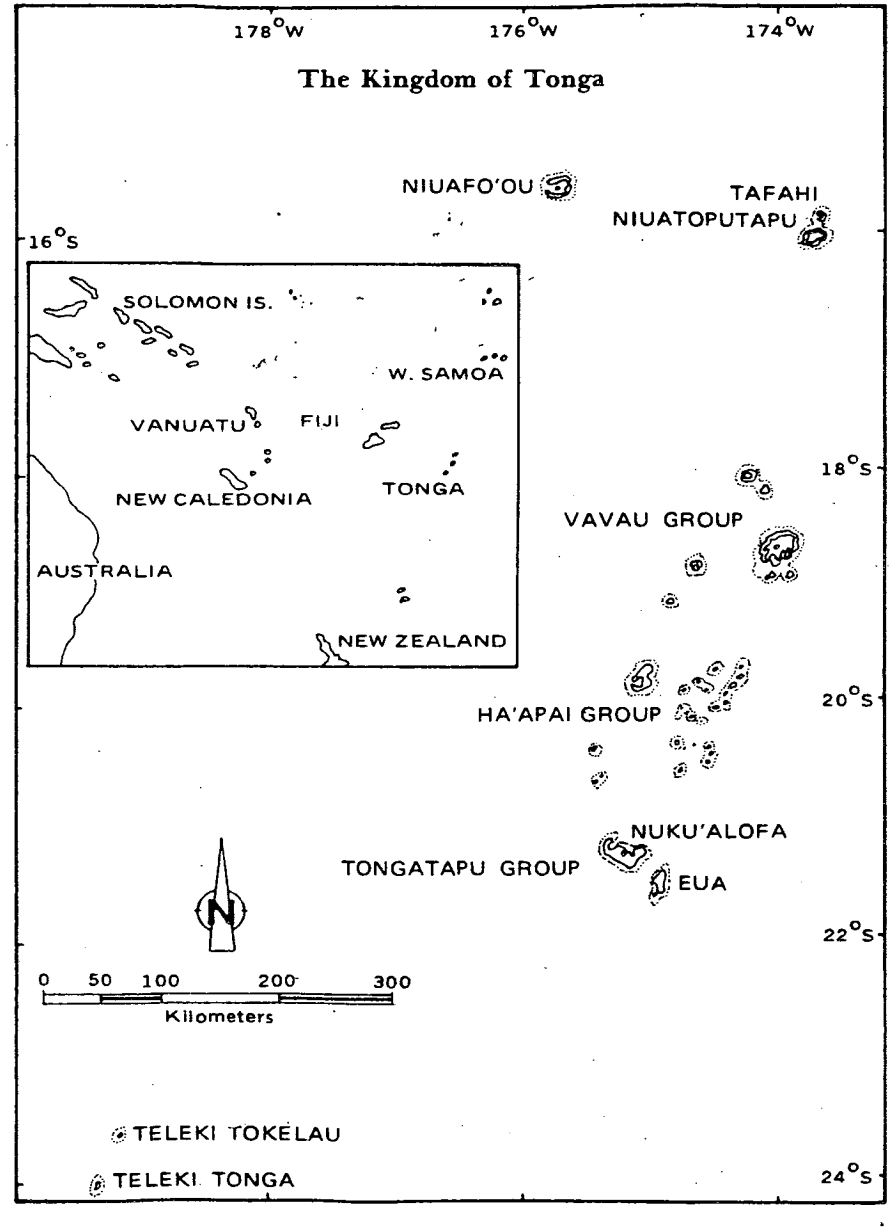
In this connection, Kami and Dillon cite a likely future need for the following services and considerations:

(i) Expansion of timber transport to encourage new industry;

(ii) Provision of freezer/chilled transport services to stimulate fisheries and agriculture;

(iii) Transport of construction materials to the outer islands for reconstruction purposes;

Map 1



Map 2

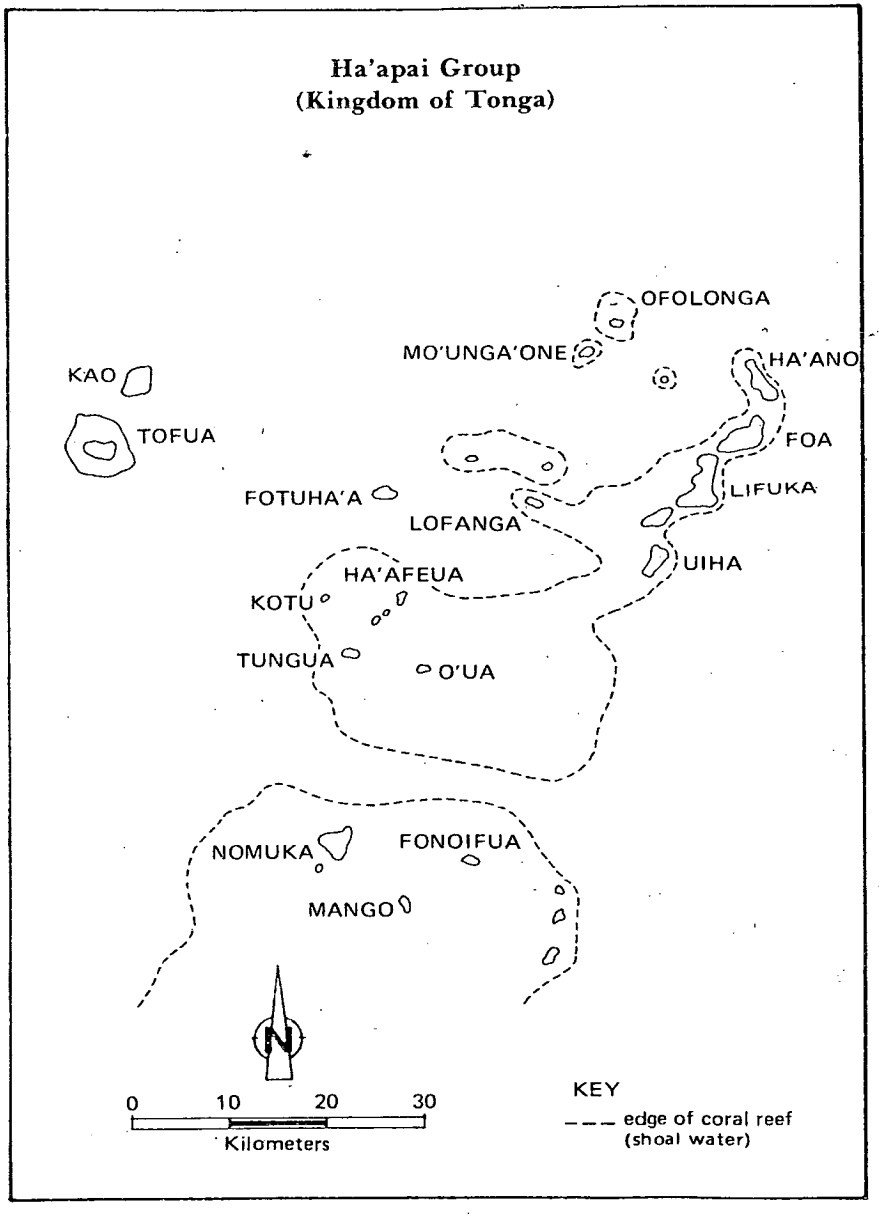
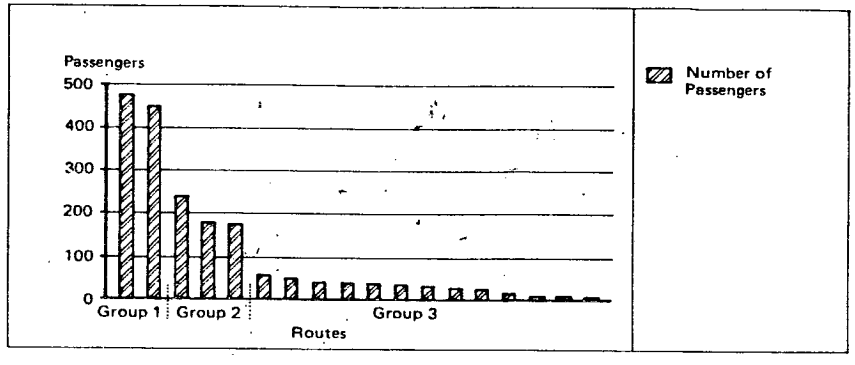


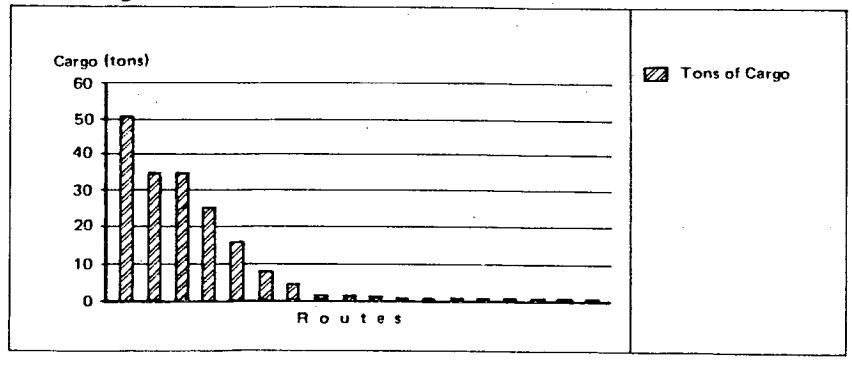
Figure 1

Ha'Apai Group, Tonga, Intraisland Passenger and Cargo Movements, December 1981

(a) Passenger Movements



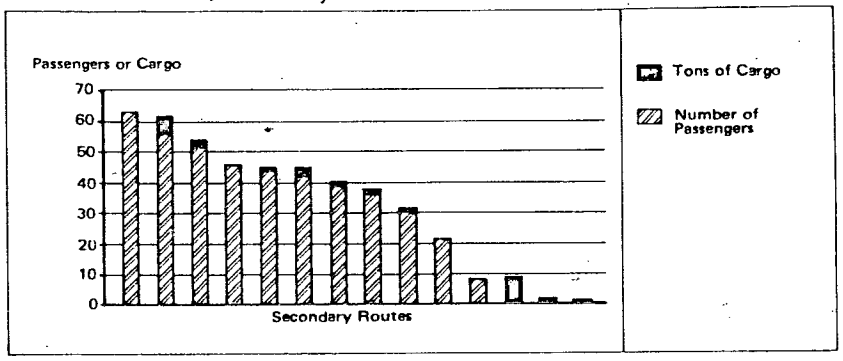
(b) Cargo Movements



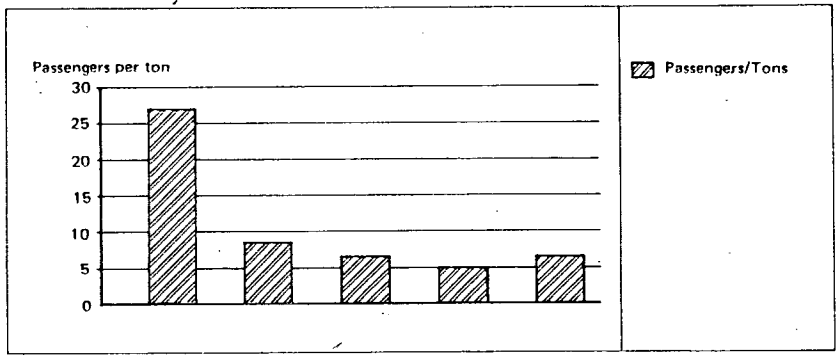
Source: Kami and Dillon, 1982.

Figure 2

(a) Comparison of Cargo and Passenger Movements, Primary Routes



(b) Ratio of Passengers to Cargo, Primary Routes



(c) Comparison of Passenger and Cargo Movements, Secondary Routes

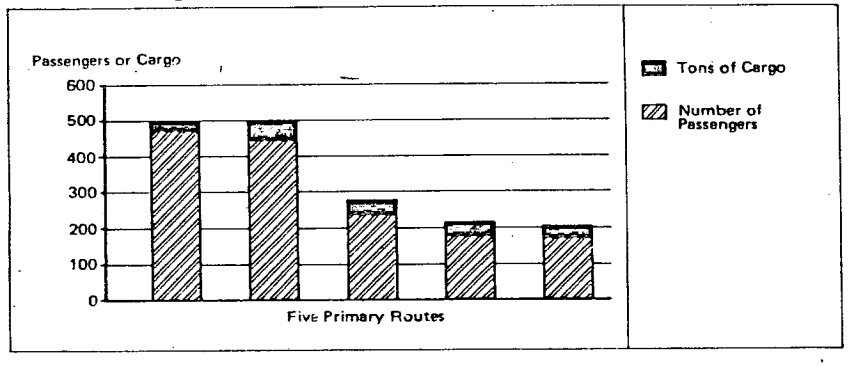
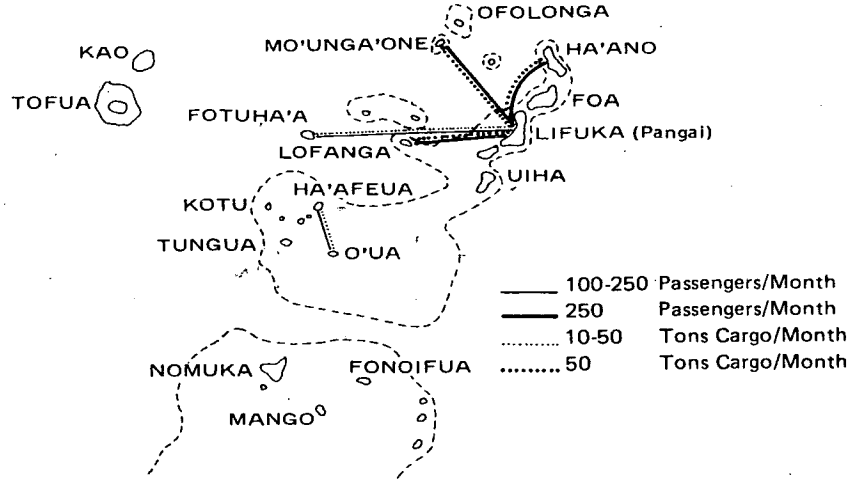
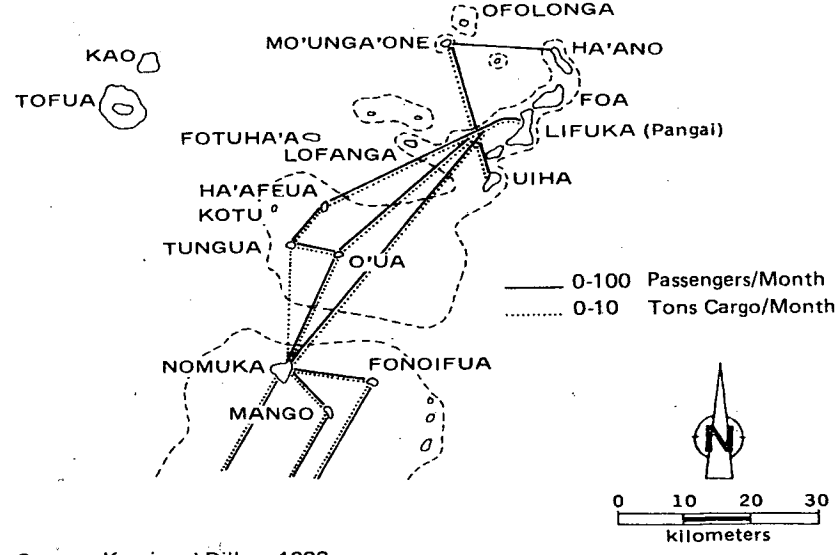


Figure 3

(a) Primary Routes



(b) Secondary Routes



Source: Kami and Dillon, 1982.

(iv) Opening up of longer routes to outlying islands, such as Tofua; and

(v) Improved standards of safety and reliability for intraisland vessels.

REQUIREMENTS FOR NEW VESSELS

Existing Primary Routes

From the data in the foregoing analysis the most attractive routes are the short, high-density primary routes which run largely within the protection of coral reefs. These routes need to be frequently serviced by craft capable of carrying both passengers and cargo. As already pointed out, the ratio of people to cargo is generally around seven passengers for each ton of cargo.

Typically, these primary routes involve the movement of between 200 and 500 people per month and a frequent service, in some cases as often as daily return trips. Typical average passenger movements are 15 to 30 per return trip, that is, 7 to 15 each way on balanced routes. The associated weight of cargo is one to two tons each way (Kami and Dillon).

From the above data alone, it is difficult to make precise deductions concerning the optimum size of vessel for these routes. To do this would require more information on the directional nature of the traffic, its seasonality and other variations. In addition, there are probably minimum unit sizes of cargo or other practical considerations which will influence vessel size. However, Kami and Dillon recommended that vessels of 30-passenger/10-ton cargo capacity would be appropriate.

The 30-passenger requirement would seem reasonable, but it is difficult to understand the requirement for 10 tons of cargo. A figure of less than half of this would seem more appropriate, to bring the relative values in line with the average of seven passengers/ton found on most of the routes. Consequently, to serve these short high-density routes, a class of vessel capable of carrying 30 passengers and four tons of cargo is proposed. Assuming a mean weight of 75 kg per passenger, the maximum carrying capacity of these vessels will need to be approximately 6.3 tons. This implies a vessel of around 20 tons total weight if conventional construction methods are used.

Secondary and New Routes

Generally speaking, secondary and new routes are over greater distances and involve traveling outside the shelter of the reefs and sometimes well

to leeward of the main group. Leaving aside considerations of cargo or passenger capacity, to carry out these functions safely the vessels will need to be larger than those required for the primary routes.

The statistics presented in Kami and Dillon do not provide much guidance on the optimum size of vessel for these routes. Indeed, if the figures alone are used, it is difficult to see any justification for increasing the service. As noted earlier, however, Kami and Dillon also outline a more general policy to expand trade within the Ha'apai group. New, regular and secure intraisland services would contribute to reviving the cash economy by providing access to appropriate markets and imposing a supply-generated demand on the local economy.

With this in mind, Kami and Dillon proposed that the vessel required should be able to carry 15 to 20 tons of cargo and up to 50 passengers. This represents a maximum cargo capacity of 24 tons and implies a vessel with a total weight of around 80 tons.

Coincidentally, such a vessel size is approximately the minimum that could reasonably be considered for regular passenger-carrying services in the open sea. While smaller vessels can of course survive even extreme weather in open oceans, they are subject to motion which for the nonsailor can be extremely uncomfortable and frightening. Such experience would not be conducive to encouraging increased intraisland transport, one of the stated aims of the new service. In view of these considerations for the routes which must be serviced, the vessel capacity proposed by Kami and Dillon is about the smallest practical solution.

OUTLINE DESIGN OF VESSELS

The existing and anticipated future demands for intraisland transport indicate the need for two different types of vessels:

(i) The short high-density routes in sheltered waters require small vessels capable of operating flexible, frequent services; and

(ii) The longer and newer routes require a sea-going vessel capable of maintaining regular schedules and carrying larger quantities of cargo.

In this paper, only the general design of the smaller vessels is considered as it seems likely that their final form will be heavily influenced by existing local practice and experience. In contrast, the larger vessel will be a new concept, opening up new routes and opportunities. Consequently, it can

more reasonably be subject to outside influences and, at least initially, be developed externally.

Small, Sheltered Water Transport Vessels

The primary requirement for these vessels is that they can carry up to 30 passengers and four tons of cargo. Given the nature of the routes which they are to service, a shallow draft of less than one meter is important. Since the route lengths are short, frequent but perhaps not extremely regular services are required, so the operating speed need not be high or particularly consistent. This latter argument, if correct, implies that these vessels could substantially rely on the wind for propulsion. This could also help to keep capital and running costs low, thus encouraging more craft to be built and expanding the transport infrastructure in a flexible and responsive way.

The combination of a capacity biased towards passenger traffic and the need for effective sail propulsion is a difficult requirement for small vessels. Passengers like to see around them and require a larger volume per unit weight than for cargo. Consequently, they need to be positioned relatively high up in the vessel. This requirement conflicts with the need for good stability if sail is carried. The smaller the vessel the more difficult this problem becomes. A brief investigation of a conventional single hull vessel design was carried out. This disclosed that the two requirements were so much in conflict that any practical design involved so much compromise of sailing performance as to render the sail little more than a safety feature. In addition, much of the deck space would be occupied by passengers, so that sail handling would be more difficult.

The solution to this dilemma may lie in a different concept altogether, a double hulled vessel, or catamaran. This concept will solve the problems of limited deck space and low stability. It also helps the associated shallow draft requirement. At this stage, the designs have not been taken further, pending local reaction and more detailed traffic information.

Open Water Intraisland Vessels

In contrast to the smaller vessels, the vessel for the longer routes can better stimulate new demand, rather than fit into an existing pattern of demand. Consequently, its design can be approached on a more fundamental economic basis, with a view to developing the most cost-effective solution to carrying a specified combination of passengers and cargo. It then remains to be seen if the resultant transport costs are competitive with local rates. If they are not competitive, the value of subsidy must be determined from the point of view of the overall economy of the island group.

Design Specification

From the traffic analysis and from study of information on the navigational conditions, the following basic parameters were fixed for the preliminary design:

Cargo capacity	20 tons
Passenger capacity	50 passengers
Draft	2.0 to 3.0 meters

Beyond these values there were no other precise figures to determine the design, but in view of various comments in Eyre and Philp and in Kami and Dillon, the following additional items were considered:

(i) Hull to be constructed in steel;

(ii) Hull form to be suitable for taking the bottom;

(iii) Fuel efficiency to be emphasized; and

(iv) Potential for sail propulsion to be fully exploited.

For reduced capital costs, the smallest vessel which would satisfy these constraints was assumed to be the best starting point for the design analysis. A stowage rate of three cubic meters per ton was used to determine the cargo hold volume and after several iterations the design shown in Figures 4 and 5 was produced. The general features of the design are:

Cargo Hold

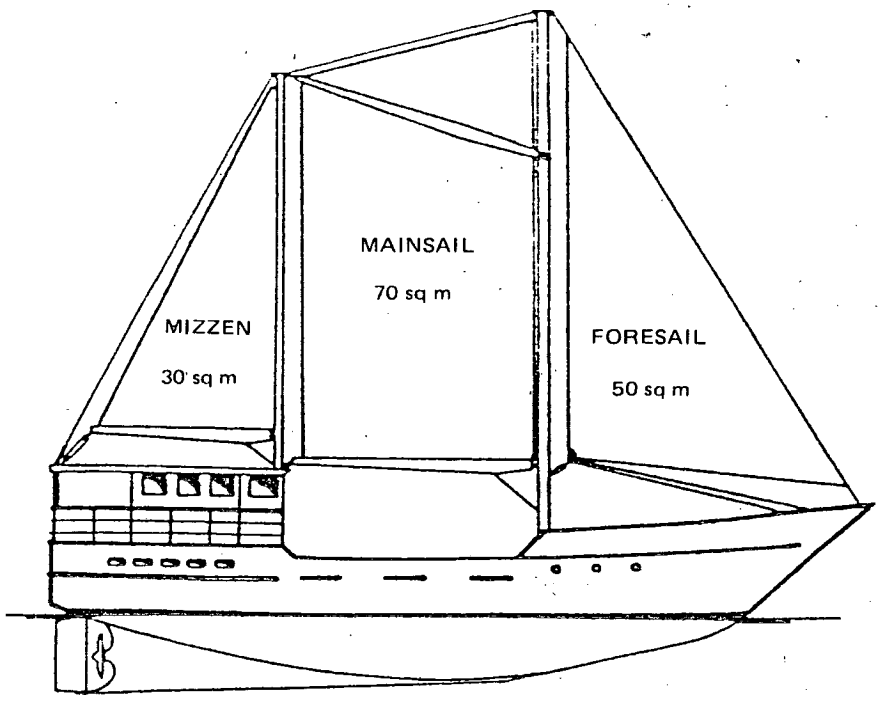
Central cargo hold space is substantially prismatic in cross section with provision for additional deck cargo, as required. Adequate volume is provided for part of the hold to be a permanent freezer section.

Passenger Accommodation

Two main cabin areas are provided, with the larger one in the after part of the vessel, where motion is least. Considerable deck space is also available above the cargo hold and a portable awning could be fitted without affecting the working of the ship. Further accommodation space is also available behind the navigating bridge. There is adequate space for crew accommodation in the forward part of the vessel. No details of the accommodation layout are given as these could only be usefully decided in the light of considerably more detailed knowledge of the operational requirements. The enclosed space available is, however, more than ample for 50 passengers, with the protected deck space serving as an additional area for passengers, if required.

Figure 4

General Arrangement and Sail Plan

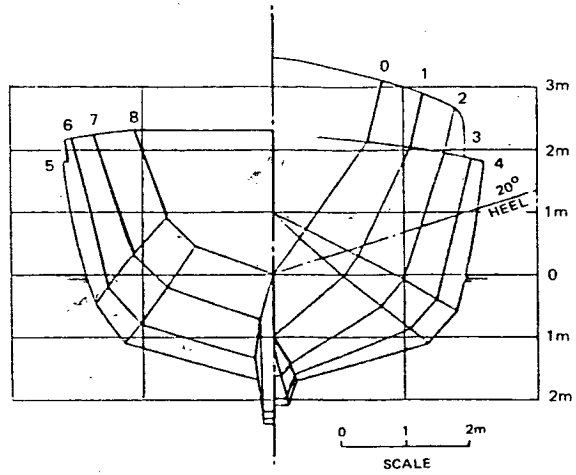


INTRAISLAND TRADING VESSEL FOR HA'APAI GROUP, TONGA

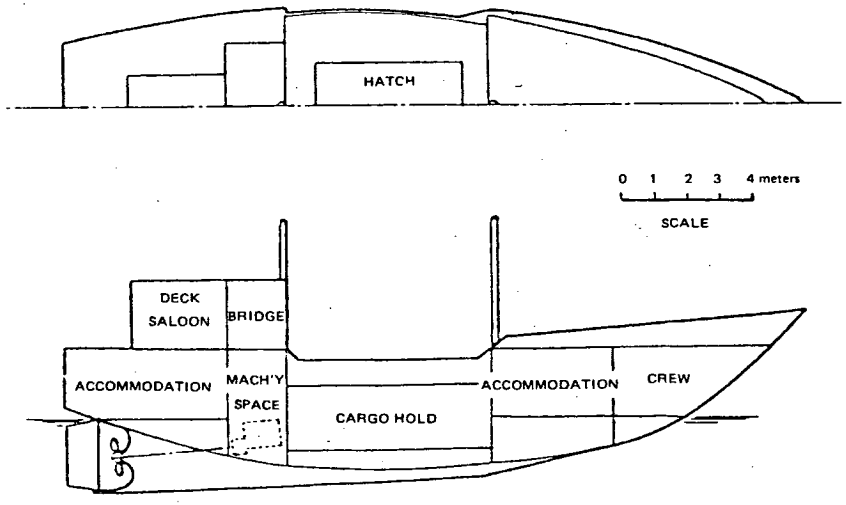
Principal Particulars			
Length, Overall	22.5m	Lightship displacement	65 tons
Length, Water Line	18.0m	Ballast	10 tons
Beam	6.4m	Cargo Deadweight	20 tons
Depth	2.8m	Passenger Capacity	50 passengers
Draft	2.4m	Working Sail Area	150 sq m
		Engine Power	40 kw

Figure 5

(a) Preliminary Body Plan



(b) Internal Layout Schematic Plan



Propulsion Machinery

A small diesel engine of approximately 40kw, with a large reduction ratio, driving a fixed pitch two-bladed propeller, is the proposed mechanical propulsion system. Adequate space exists within the engine room for generators and other equipment for ship services. The exact choice of machinery will depend upon local supply and support and the chosen operating strategy for the vessel.

Hull Form

The hull combines considerable beam with a firm midship section and a reasonably fine form. This ensures adequate stability and minimizes resistance at relatively low speeds. The forefoot is cut away to reduce wetted area and to provide good balance when under sail. The keel is raked to give good directional stability and to provide the most efficient distribution of lateral area. Forward sections are 'V' shaped and well flared to maintain dryness at sea, which is further enhanced by the high freeboard forward. The most important hydrodynamic hull parameters are shown in Figure 6, together with a prediction of the hull resistance in calm water.

Sail Plan

The sail plan is contained within the overall length of the hull. A simple two-masted wishbone schooner rig with roller furling sails is proposed. The foresail is set on a boom to provide ease of control and to facilitate setting on downwind sailing courses. The total sail area is moderate, and the maximum heel angle will not exceed 15 degrees in 96 per cent of the wind conditions experienced in the area. Practice and experience may well show that more sail could be carried with safety, but the proposed area is considered to be a good starting point.

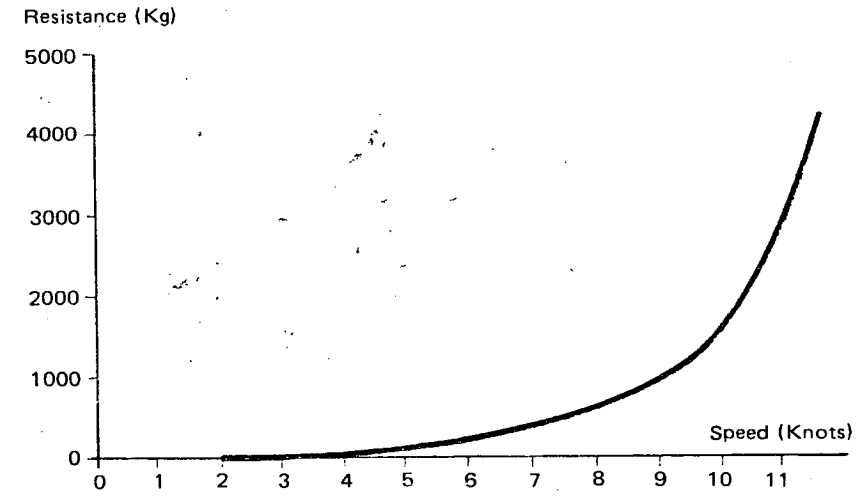
POTENTIAL FOR SAIL POWER

In the sea area around Tonga, prevailing winds are relatively light but also quite uniform in direction. The prevailing wind is from the south east, while the chain of islands runs from north-north east to south-south west. Consequently, sailing vessels making long passages between the island groups will generally experience favorable wind directions.

Within the Ha'apai group, the wind conditions are not so consistent or necessarily favorable. For present purposes two typical routes were analyzed, one at a favorable orientation to the prevailing wind and one at an unfavorable orientation. The routes selected were Lifuka/Nomuka and Lifuka/Tofua, with assumed constant headings of 040/220 degrees and

Figure 6

18 Meter Intraisland Vessel
Half Load Condition



DATA FOR RESISTANCE PREDICTION

Prismatic coefficient	.61
LCB position (% DWL)	– 3
Water line beam(m)	5.7
Water line length (m)	18
Draught (m)	1.5
Wetted surface area (m 2)	120
Displacement (tons)	75
Entrance angle (deg)	25
Midship section coeff	.75
Roughness factor (%Cf)	25

RESISTANCE PREDICTION USING GERRITSMA METHOD

SPEED (Knots)	HULL RESISTANCE (kg)			EHP (hp)
Vk	Rt	Rr	Rf	EHP
3.9	82.7	7.0	75.7	2.2
5.2	168.2	39.5	128.7	5.9
6.5	317.1	122.7	194.5	13.9
7.7	592.7	320.2	272.5	31.1
9.0	1008.2	645.7	362.6	61.7
9.7	1336.7	924.7	412.0	87.6
10.3	1976.2	1511.7	464.4	138.1
11.0	2893.3	2373.6	519.7	214.9
11.6	4281.3	3703.4	577.8	336.7

090/270 degrees, respectively. In particular, the Tofua to Lifuka course (090 degrees) is especially unfavorable. In practice, a vessel relying substantially on wind power could well be routed differently. However, it serves the useful purpose here of indicating a more or less worst case.

Wind Speed Distribution

Figure 7(a) illustrates the average annual occurrence of different wind speeds. It can immediately be seen that the majority of winds are Beaufort force four (15 knots) or less. Winds in excess of force six (27 knots) are very rare.

The thrust produced per unit of sail area is proportional to the wind velocity squared. So, in practice, the higher wind speeds will tend to make a disproportionate contribution to the average sail thrust. This is illustrated by Figure 7(b), which shows the product of the frequency of a particular wind speed with the square of that speed, to give a measure of the available wind thrust. Compared to the frequency of occurrence, the peak of the wind thrust distribution is moved towards considerably higher wind speeds, with the peak contribution coming from winds of force five, despite their relatively low frequency of occurrence of 11 per cent. To the left of the distribution it can be seen that winds of up to force two have a negligible contribution, and even at force three, which is the most frequent wind strength, the contribution is still relatively small.

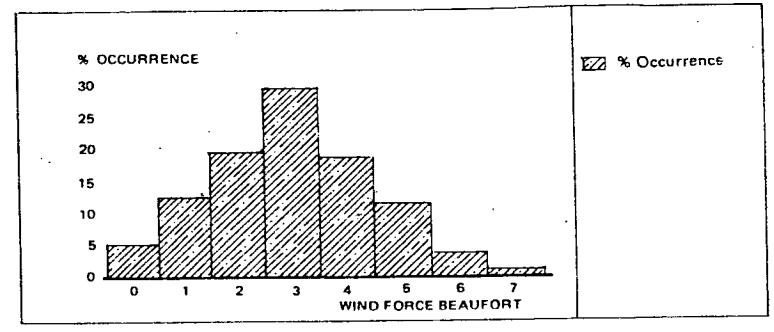
This distribution shows that unless considerable additional sail area can be set in moderate winds, the majority of wind assistance will come from the stronger and less frequent winds. For example, the contribution of force three winds, per unit area, is two-thirds that of force four. Thus, a 50 per cent increase in sail area would be needed in the lighter winds to achieve similar contributions. In practice, such an increase is unlikely on a commercial vessel.

Wind Direction Distribution

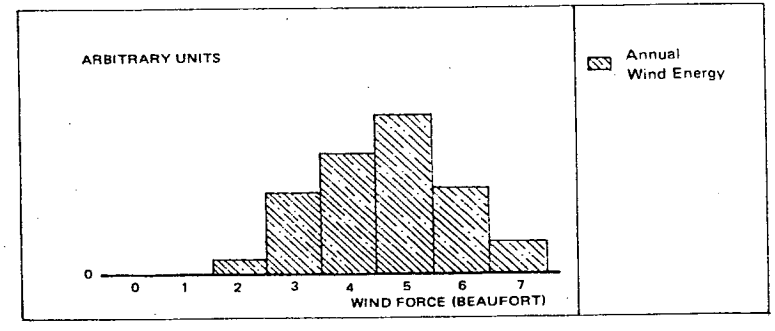
Figure 7(c) shows contours of the annual frequency of occurrence of different levels of wind energy and its associated direction. It is immediately apparent that the majority of energy lies between a direction of 060 and 180 degrees. Also shown on Figure 7(c) are the directions of the two routes selected for study.

Figure 7

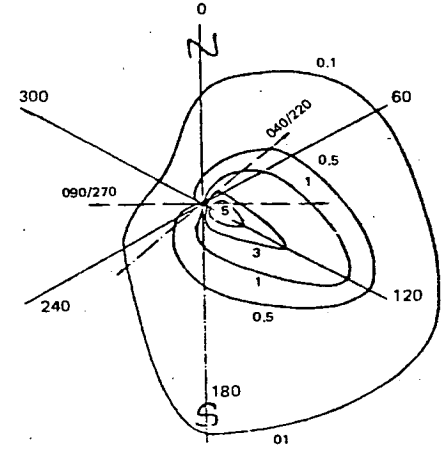
(a) Annual Distribution of Wind Speed



(b) Annual Distribution of Wind Energy



(c) Annual Wind Energy Contours
Per Cent Occurrence Against Direction



ANALYSIS OF VESSEL PERFORMANCE

With the wind data and hull parameters as input, the Gifford Technology motor prediction program was used to study the performance of the vessel under prevailing conditions.

For each case, the analysis was run for a range of uniform wind directions to give polar performance curves and predictions of the auxiliary engine power requirements. For simulation of the sail-motor operation, the analysis was run for a set of different minimum or cut-in speeds. These are the speeds at which the engine is assumed to be started and run, so as to maintain that speed until it can again be exceeded by sail power alone. Figure 8 shows a typical set of performance and power curves for an assumed cut-in speed of 7.5 knots. It can be seen from the power curves that in head winds the power requirement rises with increasing wind speed, due to a combination of additional windage and added resistance in waves. The results for performance in steady winds were then combined with wind statistics for the Ha'apai group to provide predictions of performance on intraisland services.

Speed Variation

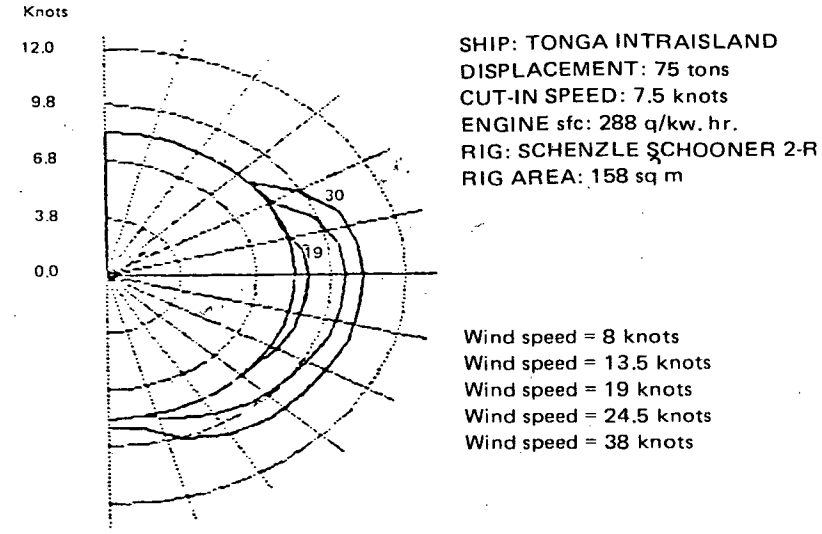
The analysis was run for minimum speeds varying from zero knots (no engine power) to 7.5 knots. Figure 9(a) shows how the average speed on the two routes varies with the minimum speed. As expected, the wind propulsion provides a greater contribution on the 040/200 degrees course; but in both cases the contribution becomes small at minimum speeds of more than six knots. Figure 9(b) shows the distribution of speed achieved on the 220 degrees course under sail alone. Similar pictures can be prepared for other cases, so that the relative effects of tuning performance to different speed bands can be investigated.

Yacht Performance Comparison

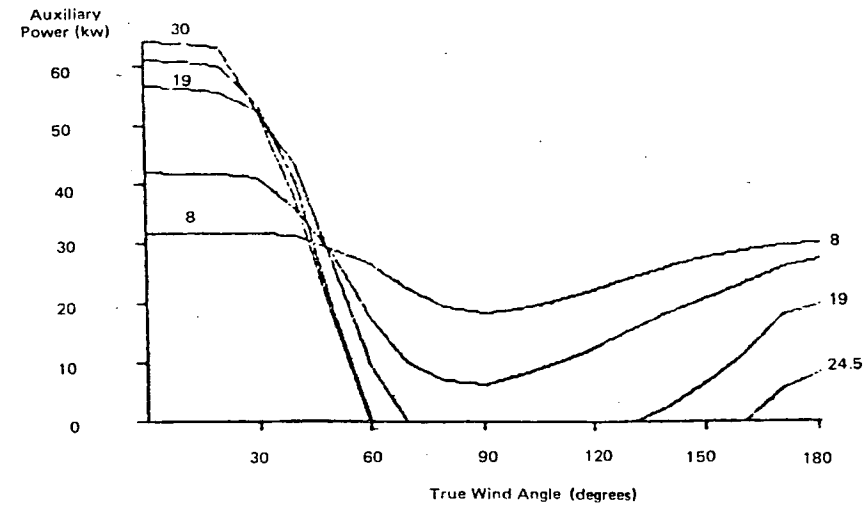
The design produced is very much a sail-motor vessel as this is expected to be the best overall solution. However, as a basis for comparison, a high-performance variant was conceived. The basic hull form is retained, but the draft is increased to four meters and the stability doubled by extensive use of lightweight composites in construction (such a vessel is not proposed as a practical alternative, but is included to demonstrate the theoretical limits to sail propulsion). In subsequent results, the curves labeled yacht refer to this vessel and the comparison is very instructive. For example, Figure 9 shows that the yacht form (which carries 70 per cent more sail) is significantly faster when operated under sail alone; but even so, the average

Figure 8

(a) Polar Performance Plot
Ship Speed (Knots) vs True Wind Angle



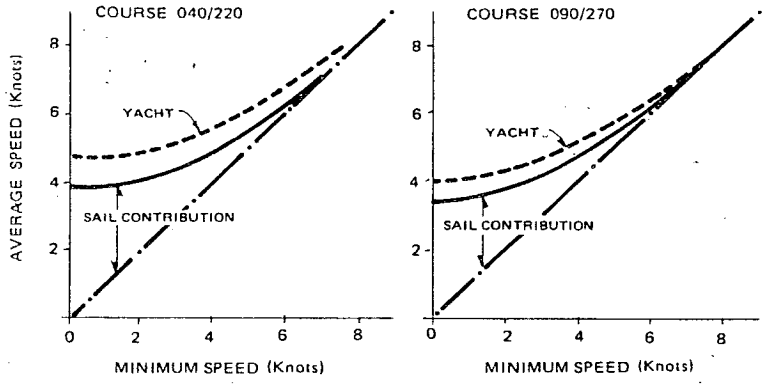
(b) Auxiliary Power Requirement vs Wind Angle
True wind Speed (Knots): 8, 13.5, 19, 24.5, 30



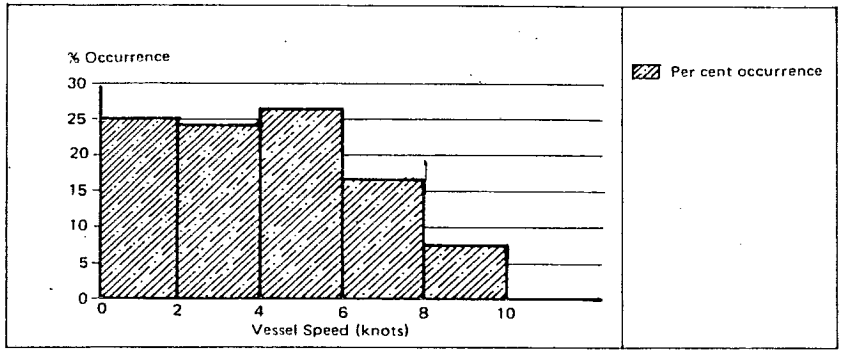
Source: Gifford Technology, 1985

Figure 9

(a) Effect of Minimum Speed on Average Speed



(b) Variation of Vessel Speed Course 220° Sail-Power Only



speeds do not exceed five knots even on the favorable route. At a minimum speed of six knots the difference between yacht and the sail-motor vessel is much reduced.

Effect of Hull Draft

For ease of navigation and for comfort when grounded, the draft of the vessel must be limited. At a minimum speed of six knots the analysis was run for hull draft between 2.0 and 4.0 meters. Figure 10 shows the results of this analysis, presented in terms of power saving (compared to motor only operation) on randomly distributed course headings.

The results show that in moderate winds (up to 19 knots) the potential power saving increases quite rapidly as the draft is increased above 2.0 meters, but levels off as it exceeds 2.5 meters. A draft of 2.4 meters was selected as the best compromise between power saving and practical expediency.

Power Variation

As in predicting the variation of speed with different operating conditions, the variation of power use can also be predicted. Figure 11(a) shows the variation of mean power with average speed on the two courses. Predictions were also made of the power requirement for a similar vessel operated under power alone. The difference between the two lines is the power saved by using sail propulsion. In general the yacht version has a fuel saving approximately 40 per cent greater, but the difference is less marked on the less favorable (090/270 degrees) course. At a more advanced stage in design, information would be required on the variation of engine power during the sail-motor operation. This information can be obtained from the analysis. Typical results are shown in Figure 11(b).

OPERATING COSTS

The costs for the vessel were estimated on the basis of information contained in Eyre and Philp, in addition to other data available to Gifford and Partners.

Capital Cost

For the vessel proposed by Eyre and Philp the total cost was estimated to be US$175,000. This is for a vessel with a light ship displacement of 71.5

Figure 10

Effect of Hull Draft on Power Saving
Service Speed = 6 Knots
Random Wind Directions

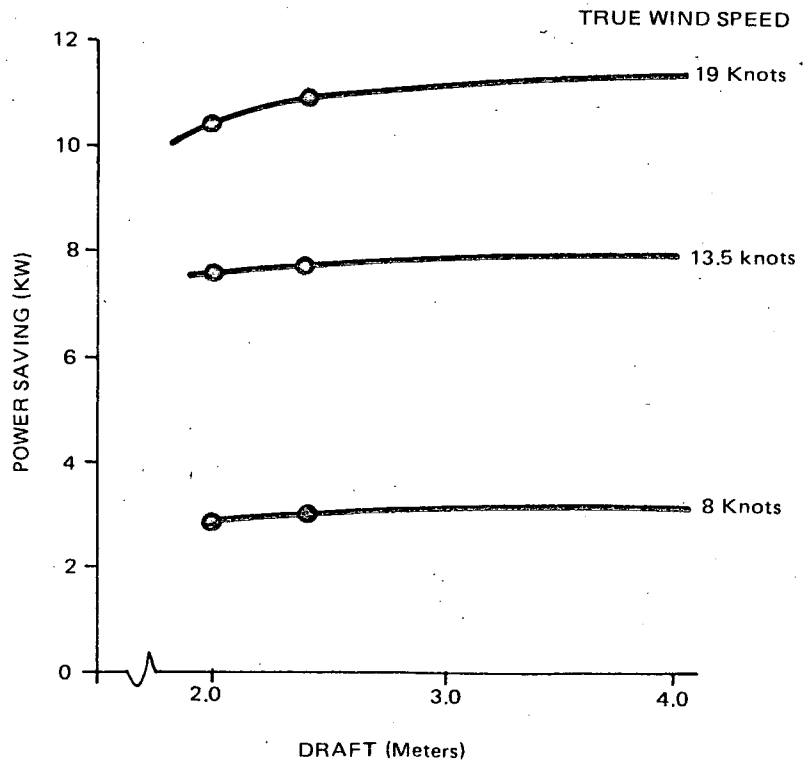
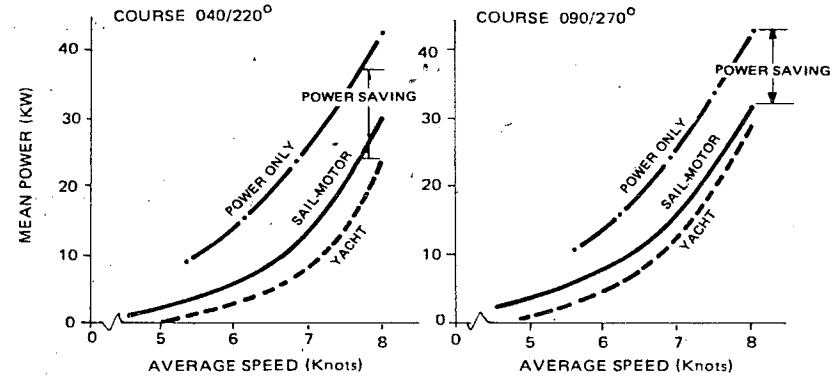
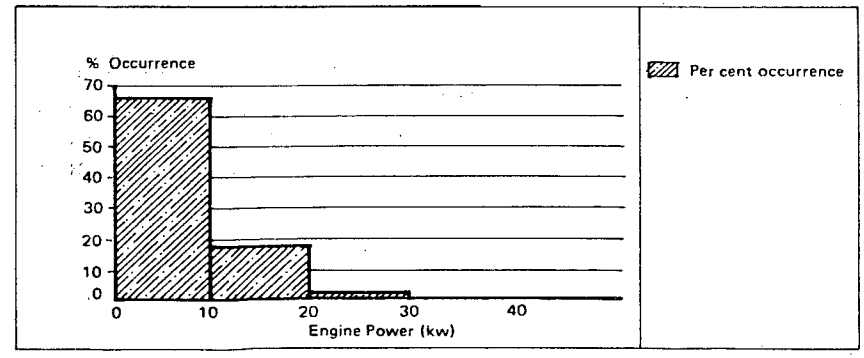


Figure 11

(a) Variation of Power Speed Comparison of Power Only and Sail-Motor Operation



(b) Variation of Engine Power Course 220 Minimum Speed = 6 knots



tons. The current design (excluding ballast) has a light ship displacement of 55 tons. For comparable vessel types, the cost per ton is roughly constant, so the capital cost can be estimated by direct proportion on weight:

$$\text{Capital cost} = 175{,}000 \times 55/71.5$$
$$= \text{US\$}135.00$$

(at an exchange rate of T$1.4 = US$1, the cost is T$189,000).

In the absence of more design details and local costs, this is the most reliable figure achievable.

Annual Fixed Operating Costs (Except Capital Charges)

On the basis of the same factors or actual figures as per Eyre and Philp, the following costs were predicted in Tongan dollars:

	(T$)
Insurance at 2.5 per cent of first cost	4,725
Officers and crew	13,110
Food and stores	1,825
Maintenance and repairs at 2 per cent	3,780
Miscellaneous costs at 2 per cent	3,780
Fixed Operating Costs (except capital charges)	27,220

Capital Charges

The magnitude of the capital charges will depend upon the availability of loans, aid or other sources of finance. However, for a more realistic assessment of the economics of the vessel, some capital charges must be included. For present purposes it is assumed that the construction of the vessel is funded by a loan which must be repaid over ten years at an interest rate of ten per cent. The annual repayments needed to service this loan are 16.2 per cent of the capital value:

	(T$)
Annual capital charges	30,618
Other annual fixed costs	27,220
Total Annual Fixed Costs	57,838

Annual Variable Costs

These costs derive from two main sources, dock charges and fuel costs. The dock or stevedoring costs were estimated by Eyre and Philp to be T$1.0 per ton and will thus vary with vessel utilization. In this form, these charges are effectively a reduction in cargo freight rate and are treated as such in this study. Fuel costs will vary with the vessels' speed and utilization. Fuel cost is given as T$0.95 per liter. Assuming a moderate engine fuel consumption of 0.25 kg/kw. hr, the cost of operation is T$0.16/kw.hr. In practice, the specific fuel consumption will vary with engine loading, but so too will the propeller efficiency. The two effects tend to cancel out and for this general level of study they can be ignored.

Vessel Utilization

The annual vessel utilization will depend greatly upon the operating conditions and traffic demand. In its usual role of carrying cargo and passengers (as distinct from special charters or other uses), the vessel is likely to be in operation for between 2,000 and 3,000 hours per year. Economic predictions are worked for these two figures to give a range of results from which sensitivities may be judged. While utilization is a primary variable, the costs and revenue also depend upon the load factor, that is, the fraction of maximum capacity at which the vessel operates.

The other factor which enters into the calculation of revenue earning potential is the turnaround time, that is, the proportion of the operating time when cargo is being loaded or unloaded, rather than actually being moved. For an ocean-going cargo vessel which operates more or less continuously, the effect of turnaround time can be examined relatively easily for a given route length. However, on the intraisland service, the operating schedule will be influenced by the need to follow a regular, convenient timetable and to keep in step with night and day. In this case, the turnaround time is less significant as it will often be 'lost' in the waiting time involved in practical operation on a convenient schedule. Thus, in the following analysis, turnaround time is ignored and this must be borne in mind when selecting reasonable annual utilization periods.

Fuel Costs per Mile[1]

On the basis of the predictions of mean power against average speed shown in Figure 11, the fuel cost per mile traveled can be estimated. The results are set out in Table 1.

Table 1
Fuel Costs Per Nautical Mile

Average Speed	Course 040/220 degrees		Course 090/270 degrees	
Knots	Power (kw)	Cost/nm (T$)	Power (kw)	Cost/nm (T$)
4	0	0	1.5	0.06
5	2.2	0.071	3.8	0.125
6	5.7	0.155	8.0	0.216
7	13.5	0.314	16.2	0.376
8	30.0	0.61	32.2	0.654
8.5	43.0	0.85	45.0	0.063

Fixed Costs per Mile

Taking the assumed values for annual utilization as the hours under way, the fixed costs per mile can be estimated for a range of average speeds. These are set out in Table 2.

1 In this paper, "miles" refer to nautical miles (nm). For comparison purposes:
1.0 nautical mile = 1.15 statute miles
1.0 nautical mile = 1.85 kilometers

Table 2
Fixed Costs Per Nautical Mile

Average Speed (Knots)	Utilization (Hours per year) 2,000 (T$)	3,000 (T$)
4	7.23	4.82
5	5.78	3.85
6	4.82	3.21
7	4.13	2.75
8	3.60	2.40
8.5	3.40	2.27

Total Operating Costs per Nautical Mile

Combining the fuel and fixed costs per mile gives the total operating costs per mile. These are set out in Table 3.

Table 3
Total Operating Costs Per Nautical Mile

	Utilization 2,000 Hours per year		Utilization 3,000 Hours per year	
Average Speed	Course (degrees) 040/220	090/270	Course (degrees) 040/220	090/270
(Knots)	T$	T$	T$	T$
4	7.23	7.28	4.28	4.87
5	5.85	5.91	3.92	3.98
6	4.98	5.09	3.37	3.43
7	4.44	4.51	3.06	3.13
8	4.22	4.26	3.02	3.06
8.5	4.23	4.26	3.10	3.13

Revenue

Figure 12 was plotted from information given in Kami and Dillon. The freight rate for cargo shows a very wide scatter, with the minimum being approximately T$0.15 per ton-mile. However, if the figures are correct, the maximum (which applies to very short routes only) can be as much as T$6.7 per ton mile, some 40 times more than the minimum. This huge range is difficult to understand and for this analysis the medium level (appropriate to longer routes) is used. It is important that this anomaly be investigated at a later stage. By contrast, the passenger rates are much more closely grouped and for longer routes a mean value of T$0.05 is used.

The revenue will depend upon the load factor of the vessel. It is set out in Table 4 for a range of values, assuming that the same load factor applies for both passengers and cargo. This assumption may not actually apply in practice on individual runs; but on average over a year it may well be valid.

Table 4
Revenue Per Nautical Mile[a]

Load Factor (%)	Cargo T$	Passengers T$	Total T$
33	0.88	0.83	1.71
67	1.76	1.66	3.42
100	2.67	2.50	5.17

a These figures include an allowance for stevedoring charges.

Break-even Operating Conditions

Figure 13 shows the variation of operating costs and revenue with the parameters considered. From this diagram it is apparent that, for the examples chosen, the optimum operating speed is 7.5 to 8.0 knots, speeds at which the sail power makes a negligible contribution to average speed and gives a power saving of approximately 25 to 40 per cent. Within the accuracy of the plotting curves the difference between the two different courses is lost. This is because different headings affect only a small proportion of

Figure 12

Variation of Cargo Rate and Passenger Fare with Route Length

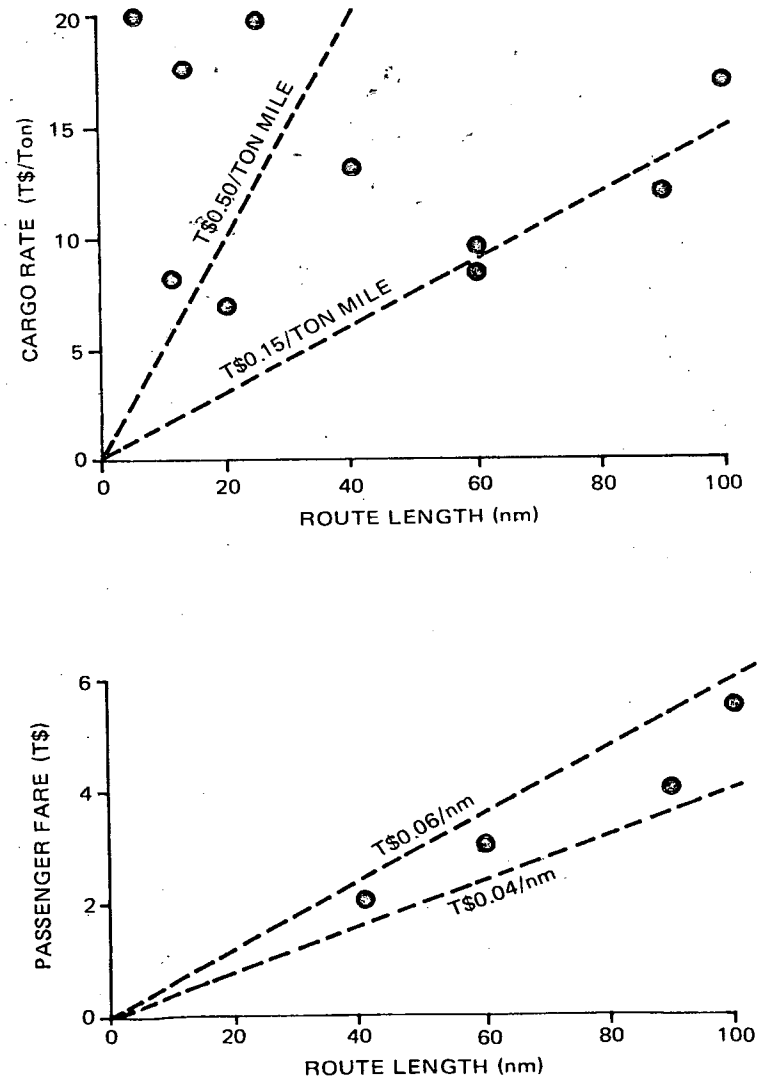
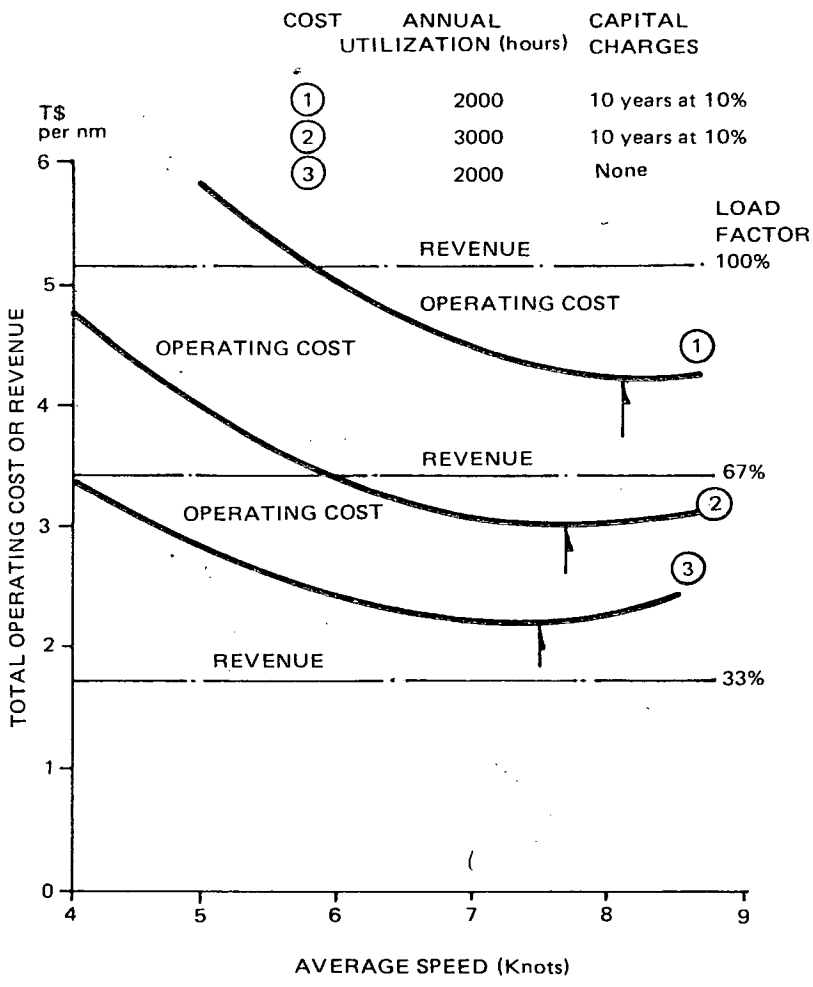


Figure 13

Operating Costs and Revenue Variation with Speed and Utilization



fuel use, which is in turn only a proportion of the total cost. As a consequence, the remaining discussion ignores the distinction between the two routes.

The three curves plotted in Figure 13 represent a wide range of operating conditions. The top curve (1) is for an annual utilization of 2,000 hours (approximately seven hours per day for 300 days) and assumes that annual capital repayments are made. In this case the minimum operating cost is T$4.2 per mile. To achieve this level the vessel would need to operate at a load factor of 82 per cent, a figure which is unlikely to be achieved in practice.

However, if the annual utilization is increased to 3,000 hours (approximately 8.5 hours per day for 350 days) then the minimum cost drops to T$3.0 per mile (curve 2). This level can be met by revenue from a 58 per cent load factor, a much more practical level.

Finally, if capital charges are waived, the minimum cost drops still further and for 2,000 hours operation becomes T$2.2 per mile. At this level a load factor of only 43 per cent is required for break-even operation.

Influence of Capital Charges

As also shown on Figure 13 the capital charges have a strong effect on the operating costs. At the rate selected (loan repayment at 10 per cent over ten years) the capital charges make up just over half the fixed costs, which are in turn a large proportion of the total costs. This breakdown is illustrated in Figure 14(a) for a 3,000 hours per year operation. The minimum value of total cost for this case occurs at an average speed of 8.0 knots.

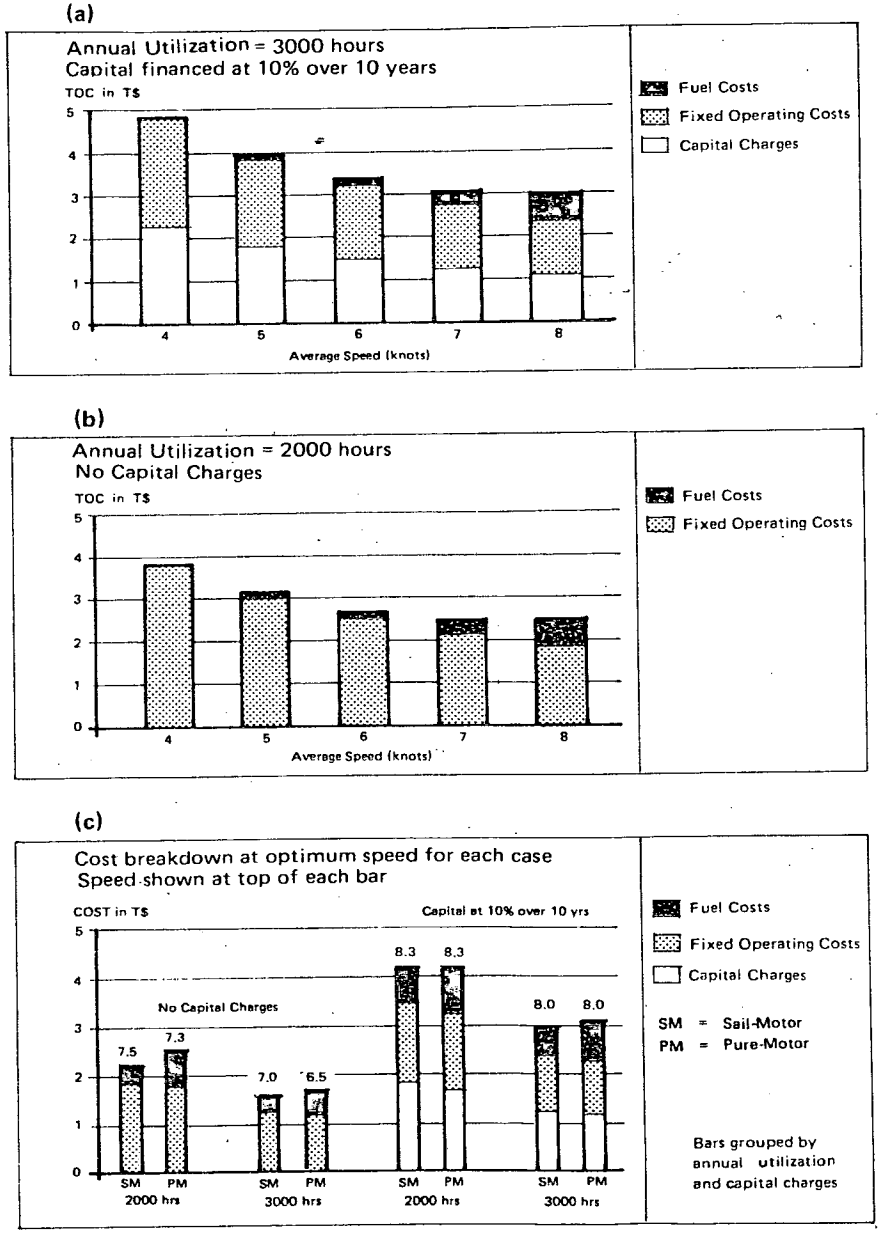
In the event that the operation does not have to service the capital, the total costs obviously drop, as shown for a 2,000 hours per year operation in Figure 14(b). In addition, the minimum value occurs at a lower average speed.

Value of Sail Assistance

Whether or not the use of sail power is justified will, in economic terms, depend upon the balance between fuel savings and capital costs. A sail-assisted vessel will be more expensive due to the cost of installing the sailing rig. Although it may be able to use an engine slightly smaller than for a power-only vessel, to achieve comparable average service speeds, the difference in capital costs due to this difference will be small. Also, there may have to be additional complications in the transmission system of the sail-assisted vessel to allow for extended operation at low power.

Figure 14

Breakdown of Total Operating Costs (TOC)



In the case of the vessel under consideration, the sail rig cost is likely to be US$100 per meter length of vessel, that is T$21,000 in total. This represents approximately 11 per cent of capital costs. To assess the economic value of the sailing rig a cost prediction was made for a pure motor vessel which is set out in Table 5 for 10 per cent over ten years capital charges.

Table 5
Cost Prediction for Motor Vessel

Average Speed (Knots)	Fuel Cost (T$/nm)	Total Cost 2,000 Hrs	T$/nm 3,000 Hrs
6	0.379	4.91	3.40
7	0.604	4.48	3.19
8	0.873	4.26	3.14
8.5	1.013	4.21	3.14

The minimum values of total operating cost are T$4.20 and T$3.14 at 2,000 hours and 3,000 hours utilization, respectively. The associated speeds are 8.3 and 8.0 knots. These costs are close to the equivalent sail-motor vessel costs of T$4.24 and T$3.04. Within the overall accuracy of the analysis, the difference between the figures is not significant and it can be concluded that, under the assumed conditions, the sailing rig gives no economic benefit.

However if capital charges are reduced the picture changes. If there are no capital charges at all, the sail-motor vessel is significantly more economic. For example, at 2,000 hours utilization the minimum costs are T$2.25 for the sail-motor vessel and T$2.56 for the motor only vessel. The comparisons described in this section are shown in Figure 14(c).

Effects of Fuel Price

At the optimum operating points the motor-sail vessel uses between 25 and 40 per cent less fuel than the motor only vessel. Consequently, it will be less sensitive to increases in fuel costs and is therefore preferable in the longer term. As fuel prices rise, the optimum operating speed will reduce. This effect will be less marked on the sail-motor vessel which will tend to have a higher optimum speed than the motor only vessel.

This difference arises because under appropriate financial conditions a sail power contribution is, in economic terms, equivalent to a reduction in fuel prices. An examination of the optimum speeds marked on the bars in Figure 14(c) shows the magnitude of the speed differences between the two modes of operation. In the case of no capital charges the differences are significant; but these differences disappear as capital charges increase. This is because the capital charges on the rig investment eventually reach such a level that the wind power contribution is no longer 'cheap fuel' and the speed difference is adjusted accordingly. In the present example this turnaround happens to occur at a capital charge level very close to that selected.

Potential for Design Refinement

While the vessel design as presented in this paper was the subject of some initial optimization it should not be considered the final optimum. The design could be readily refined by using the same approach followed in this paper, but with more detailed information on the operating profile and local costs and conditions. In particular, more attention could be directed to developing the match between auxiliary power and sail power. The present design has a conservative sail area and the yacht concept has indicated that additional fuel savings will result from more sail. This would require a vessel with more beam and more ballast. Whether the added costs of these changes, which affect hull resistance, construction cost and the additional rig costs, are justified by the fuel savings, will depend primarily on the financial basis of assessment.

A comprehensive study would be possible with the availability of more precise details and lead to the most cost effective design possible.

CONCLUSIONS

This paper has made a preliminary assessment of requirements for intraisland transport in the Ha'apai group and the need expressed by Eyre and Philp, 1982, for two different types of vessel has been supported.

For short routes in protected waters, vessels with a capacity of 30 passengers and up to four tons of cargo are required. These small vessels, in particular, appear to benefit from a large proportion of sail propulsion. To provide adequate sail area, high stability is required and a double hull design is expected to be the best concept. It will also have the additional advantage of providing a large deck area well suited to passenger transport and a shallow draft to meet the limitations imposed by extensive areas of shoal water.

For longer routes between groups of islands, a single hull, larger vessel is indicated, provided that projected levels of demand are realized. To ensure a safe, reliable service, carrying the anticipated cargo and passenger traffic, this vessel must have a capacity of 50 passengers and 20 tons of cargo. On the basis of the information available for this paper, the present levels of transport demand alone cannot justify the provision of such a larger vessel. However, projections of future demand and the concept of a supply lead demand indicate that the vessel could be justified.

By combining a highly efficient mechanical propulsion system with sail power, the resulting design is fuel efficient and at a moderate load factor appears capable of operating economically within the locally prevailing freight rates and passenger fare structures.

CASE FOR SAIL-MOTOR

For the selected conditions, the case for sail power depends most directly on the capital charges. At moderate rates (10 per cent interest on a ten-year loan) and present fuel prices, the benefit is marginal. However, if fuel prices rise or if the high propulsive efficiency assumed cannot be realized, then the case for sail assistance will improve.

Even in the case of marginal economic justification, the provision of a sailing rig can have other positive advantages. It is a valuable safety feature in the event of engine failure and provides motion damping for the comfort of passengers and crew.

As capital charges become lower the case for sail assistance also improves, and if there are no charges at all, the benefits are significant. The fuel saving in this case amounts to almost 50 per cent. However, since overall fuel use is low due to fuel efficient mechanical propulsion, the total reduction in operating costs is only 12 per cent.

In view of the preliminary nature of this study these figures should be considered as indicative of trends only. However, the tools can be used to refine the analysis, and the results of such optimization are expected to improve the case for sail assistance.

Finally, the most crucial point of all is the wind data. The best available sources in the United Kingdom were consulted, but further investigation may reveal other data. If it indicates that mean wind speeds are only a few per cent higher than those already used, the value of sail assistance will be much improved. Other studies in locations where wind speeds are higher have convincingly demonstrated the value of sail assistance, even when financing is only available at short-term commercial rates.

REFERENCES

1. Eyre, J. L., and C. E. Philp, "General Purpose Sailing Vessel to Service Ha'apai Group," UNDAT, 1982.

2. Kami, S., and R. Dillon, "Intraisland Shipping in Ha'apai, Issues Relating to Private Boat Operations," Central Planning Department, Kingdom of Tonga, 1982.

QUESTIONS AND ANSWERS

Q: What about the very small boats that would comprise most of the vessels in Tonga? Why were these not considered under the study? (Prof. H. C. Brookfield)

A: I have no information on these boats. We wanted primarily to design a vessel needed to expand Tonga's economy. Whether the design presently suggested is really the optimum design for Tonga, I cannot say.

Q: I would like to ask about the ballast which is almost one-half of the deadweight of the proposed design. If this were converted to cargo capacity, it would increase profitability. Is this permanent ballast to compensate for the high center of gravity of the vessel? (Mr. R. A. Oliveros)

A: It need not be permanent ballast. Providing the captain of the ship is aware of the extra problems involved in a sailing vessel, he could arrange to stow cargo so as to provide needed stability. Ten tons of ballast is really only a small proportion of the total displacement of the vessel.

Q: Regarding the economic analysis, the operating speeds indicated appear to be rather high for this size of vessel. The make-up of the operating costs indicate that with a fixed utilization of 2,000 hours, the variation in speed means that at four knots only 8,000 miles are sailed per year, while at eight knots, it is 16,000 miles. I feel that a better method would be to adopt a fixed range which will probably be defined by social needs, thus making speed and fuel the only variables. This would flatten the curve of operating costs and reduce speeds.

For many of the Pacific island states shipping services mainly provide a social need. Economics may have to take second place and substantial subsidies are often necessary. In these cases, the vessel has fixed annual charges, can do little to increase revenue, and is underutilized. In these cases it is preferable to reduce absolute cost of fuel, which is a drain on foreign exchange, by adopting slower operating speeds. The economic objectives of services which can generate additional revenue are quite different from some of the services operated in smaller Pacific states. Could you comment on this? (Mr. G. Davison)

A: I would agree entirely with the points made about the social justification of intraisland shipping services. However, these are essentially local judgements which, given our knowledge of Tonga at the time the study was undertaken, we were not in a position to know or even anticipate. Consequently, we set out the results in a way that was an attempt to given an overall picture of the operating costs from which data could be selected to fit particular needs.

For example, taking the concept of constant range (say 16,000 miles) rather than constant utilization, the following figures can readily be derived from the information contained in the section on operating costs.

Speed (Knots)	Utilization (Hours)	Cost /mile (T$)
4	4,000	3.6
5	3,200	3.6
6	2,666	3.8
7	2,285	4.1
8	2,000	4.2

Graphically this is essentially a cross plotting exercise on Figure 13. The result, as correctly predicted by Mr. Davison, is that the cost curve is flatter and that the optimum speed is much lower, around 4.5 knots. Whether this is any more realistic is open to debate. At 4.5 knots the annual utilization is almost 3,600 hours, or ten hours per day every day of the year. For an intraisland vessel, for which night operations might be limited by navigational hazards, this would seem to be an optimistic target. Consequently, to achieve the target range in practice the speed will have to be increased so that the practical optimum is again different to that predicted by artificially restrained analysis. The operation of an intraisland vessel is very complex and the paper was not intended to provide a particular answer. Instead it is a tool which, with the right input from a full understanding of all the factors affecting operation, can be used to predict operating costs and assist in making judgements about different strategies and design decisions. This flexibility has been at least partially demonstrated in the answer, insofar as Mr. Davison's suggestion for alternative assessment criteria was readily evaluated using the published results.

The Retrofitting of Sail to Two Existing Motor Ships of the Fiji Government Fleet

R. Gowan MacAlister*

INTRODUCTION

In recent years, much technical and practical development has been achieved for recreational craft and for large commercial sailing vessels. Sails are also being developed for numbers of small fishing craft in countries where fuel costs are destroying the viability of motorized fisheries. However, little work has been done to evaluate the practicality of retrofitting sail to existing small cargo and passenger carrying motor ships which represent a significant proportion of the world's fleets.

The Asian Development Bank and the Government of Fiji have specifically addressed this subject by investigating the Fiji fleet of typical interisland vessels. Island communities rely heavily on marine transport which consumes a proportionately large percentage of the fuel and foreign exchange budgets.

The project planned to retrofit some of the Government vessels and to evaluate the technical, economic and social results by monitoring the ships during normal commercial service. The objectives included an economic analysis of existing fleet operations, to provide a basis for sail-related economic benefit analysis, and an upgrading of theoretical techniques for predicting sail-motor performance with this type of vessel. For the latter study, MacAlister Elliott and Partners associated with Dr. C. J. Satchwell of Southampton University, who analyzed the results and compared them with mathematical models.

Essentially this has been a practical experiment on a vessel which is typical of thousands around the world in communities where fuel costs are

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a severe burden. The results have shown excellent rates of return and the economic and technical systems now exist to confidently assess the potential for auxiliary sail in any fleet of small motor ships.

BACKGROUND

The Fiji Archipelago is some 2,750 km northeast of Sydney, Australia, and 1,850 km north of Auckland, New Zealand. Fiji is made up of about 300 islands scattered over about 250,000 sq km of ocean. About 100 of the islands are inhabited. Most of the population live on the largest island, Viti Levu, which contains 10,400 sq km out of the total land area of about 18,250 sq km. The other large island in the group is Vanua Levu which contains about 5,500 sq km of land area.

ENERGY AND TRANSPORT

Fuels

The main fuels are imported from Australia and Singapore. Automotive fuel imports and re-exports are shown in Table 1. Re-exports consist mainly of bunkers for foreign ships.

Table 1
Imports and Re-exports of Automotive Fuel

	1979	1980	1981	1982
		(Million liters)		
Imports	122.8	130.2	146.1	158.1
Re-exports	42.1	44.8	40.8	39.3
Net imports	80.7	85.4	105.3	119.8
		Value in F$ Million		
Imports	17.1	28.1	38.4	44.0
Re-exports	5.5	10.7	11.7	11.8
Net imports	11.6	17.4	26.7	32.2

Source: Bureau of Statistics, Fiji

Of these totals, only about one-sixth is used in shipping. Of this one-sixth, two-thirds of the fuel is used by fishing vessels and one-third by Government and private ships.

Fuel Cost Inflation

Although the Monasavu hydro-electric scheme saves about F$20 million per year, in the years 1970 to 1980 the cost of fuel rose 14 times, consumption rose by 70 per cent and the total oil import bill rose nearly 25 times. Fuel bills cannot be judged, however, without taking into account the export prices which are related to them and to the general standard of living. Even so, total oil imports as a percentage of gross domestic product rose from 10 per cent in 1970 to 25 per cent in 1980.

Despite the recent and probably temporary drop in world market prices for many grades of oil, the trend of increasing real prices is likely to become a significant factor in the well-being of many developing communities in the next decade.

Social Considerations

The Fiji Government's objective since independence has been to foster a sense of national awareness and national identity. A fragmented society is an inherently unstable one. One important means of fostering such unity is the provision of adequate communications and transport between the islands, to allow the spread of social benefits and the strengthening of community relationships. Even when people leave the islands, strong links are maintained with their homes, remittances are made and the possibility of traveling home is considered important.

Traditional Communication

Traditionally, communications between islands were preserved by visits of trading vessels calling for copra and selling manufactured goods and by use of locally built canoes. Recently, however, the trading vessels have made insufficient profit for reinvestment, and the fleet has grown old. In 1981, the average age of privately owned ships providing interisland services was 22 years. The costs of fuel, repairs and cargo handling and port charges have continued to increase.

PROJECT INCENTIVES

This brief analysis identifies:

(i) The growing cost of imported fuel;

(ii) The need for low fuel costs in the interisland trade which is considered essential to the socioeconomic well-being of island communities and for the development of tourism;

(iii) The reluctance of traders to replace their vessels while profits are low, which has already led to the decline of adequate interisland sea services;

(iv) The worsening service for copra which, as one of the few cash crops in the island communities, assumes an importance unrelated to the modest tonnages shipped. This is aggravated by the present policy to build small copra mills on smaller islands such as Vanua Balavu and Lakeba which will reduce the transport services from Suva because there will be lower volumes of copra cargoes to be brought back;

(v) The heavy responsibilities of the Government in providing interisland emergency services and supporting commercial and social services, especially to the Eastern and Northern Division of the outer islands; and

(vi) The burden on the outer-islanders of costs for goods inflated by high freight charges and the need to accept high stock levels because of erratic transport services.

If fuel costs can be reduced, the profitability of the interisland trade can be restored. The operating costs of the Government service fleet can be reduced and the nation's fuel imports minimized. Auxiliary sail has the potential for reducing fuel costs and also has the advantage that it can be retrofitted to existing vessels.

VESSEL SELECTION AND DESIGN CONSIDERATIONS

Selection

The Government fleet was studied to choose the most suitable vessel for the sail retrofit project. The project budget allowed the initial retrofitting of only one vessel.

Selection was based on the following criteria:

(i) Physical suitability of vessel and layout;

(ii) Hull parameters and stability;

(iii) Vessel operation and tasks;

(iv) Vessel routes and passage lengths; and

(v) Age and condition of vessels, refit plans and remaining years of service.

The Project aimed to be representative of typical small motor ships. Specialist vessels such as medical boats stationed in the outer islands, floating cranes and tugs, were not considered suitable. The Governor General's motor yacht was also reluctantly not selected. Landing craft type vessels play an important role in interisland transport although their fuel efficiency is very low. While such ships could be designed to benefit from wind assistance, retrofitting existing craft is not easy and is beyond the scope of the Project.

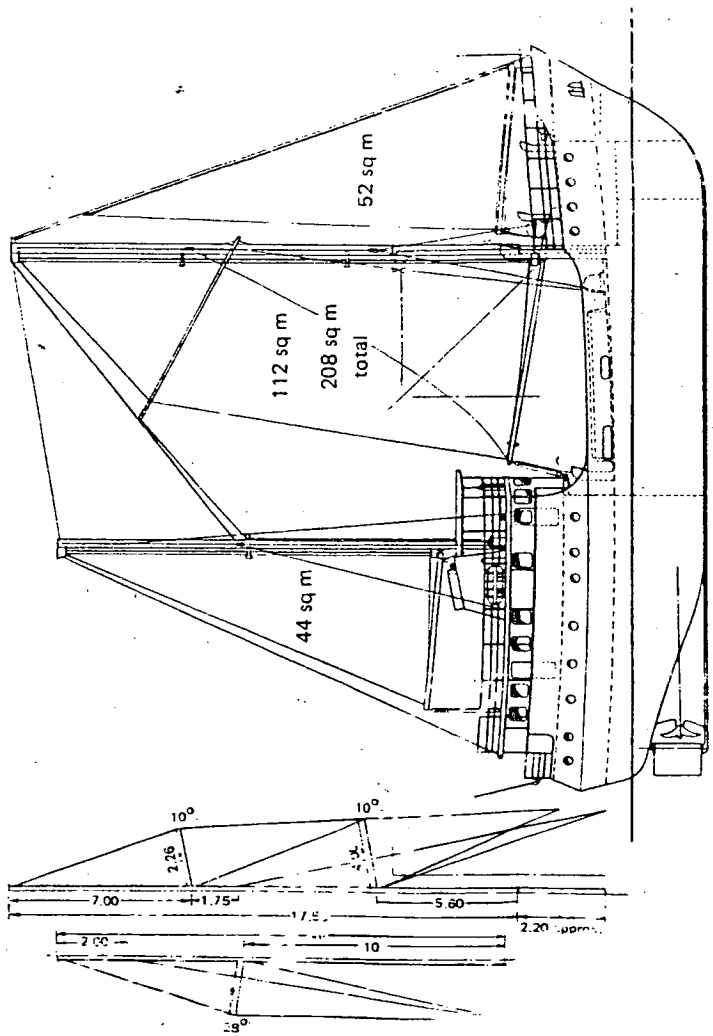
Elimination of these vessels reduced the choice to the cargo/passenger vessels providing general services such as the *Degei, Na Mata-I-Sau, Dausoko, Tabu Soro, Rogovoka, Daunivosa* and the two vessels already considered as auxiliary sailing vessels, the *Cagidonu* and the *Kapawai*. The two most suitable vessels were the relatively new (four and six years old) *Dausoko* and *Na Mata-I-Sau,* respectively. Stability tests showed that the *Na Mata-I-Sau* was slightly more stable and her superstructure was more suitable for retrofitting sail. Both ships are powered by a single Detroit diesel engine, as are many ships in the fleet. These engines were not considered ideal for the Project due to poor part load operation. The *Na Mata-I-Sau,* of 274 gross registered tons (grt) and 60 passenger capacity, is used for general interisland service and is representative of small motor ships in many parts of the world. She was therefore selected as the Project vessel (see Figure 1 and Plate 1).

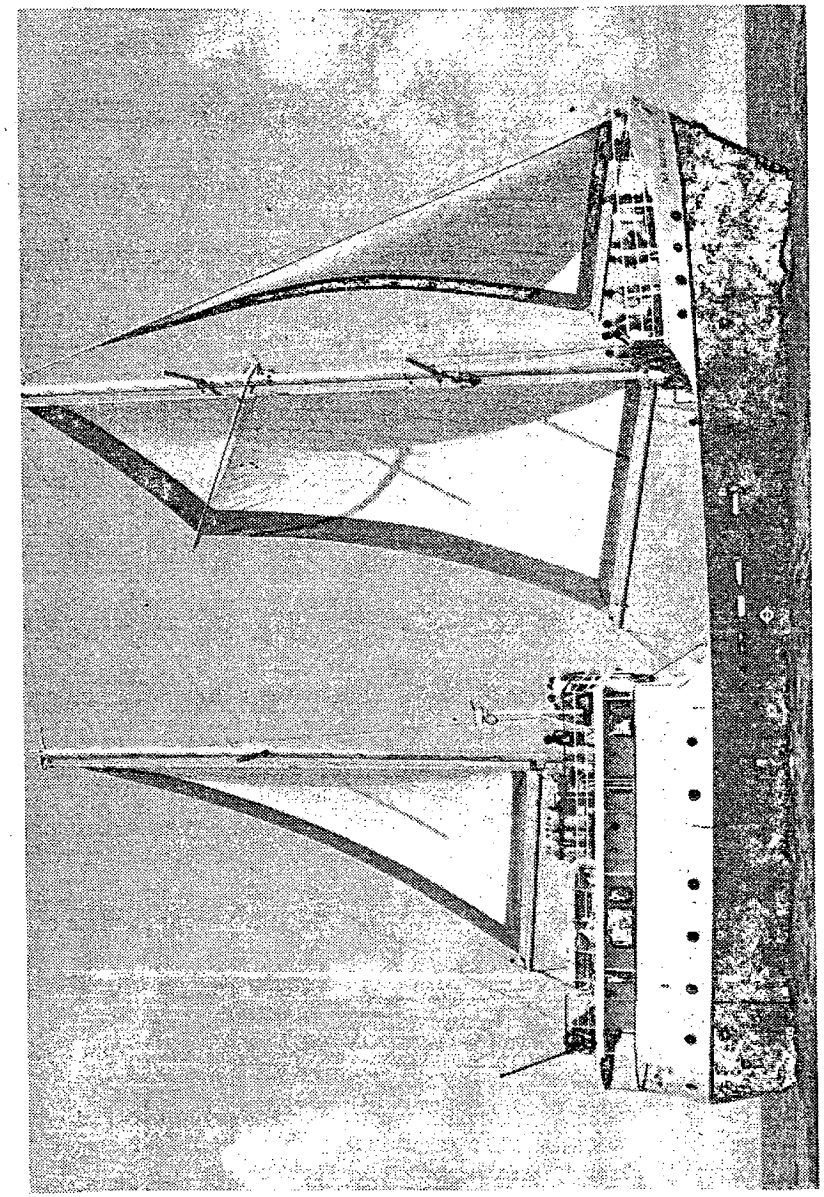
Technical Appraisal

A technical appraisal was carried out on *Na Mata-I-Sau* to ascertain the relevant parameters to enable the rig to be designed and retrofitted. An inclination test was performed by the Consultants and the crew, using 12 x 250 liter drums of water as weights. Hydrostatic and stability data were computed in the United Kingdom. In conjunction with the design office from the Suva Government shipyard, the *Na Mata-I-Sau* was physically examined to assess structural configurations and strength in way of likely mast step, stays, sheet blocks and other highly loaded areas. The main

Figure 1

Experimental Sail-Retrofit Vessel
Na Mata-I-Sau (274 grt)
(Total Sail Area 201 sq m)





Vessel under full sail in a light breeze with engines on slow speed. In this situation the vessel is making her normal operational speed of about 8.5 knots whilst achieving about 30 per cent fuel savings compared with engine alone.

engine, exhaust system, the auxiliary power and electric systems were also studied.

Design Considerations

The design of the sailing system was influenced by financial, operational and technical considerations. The Consultants were careful to observe existing operational practices at sea and to examine existing attitudes to ship's equipment and in particular, the idea of sail power. Experience with the sailing vessel, *Cagidonu* and other vessels in the commercial fleet previously carrying sail, indicates that auxiliary sail will not be used if there is a high level of stowing, trimming and handling required. The budget for the actual retrofitting of *Na Mata-I-Sau* was US$40,000 to include hardware, shipping and shipyard work at Suva. This budget precluded systems requiring specially manufactured equipment and effectively prevented the use of high technology wind lift devices such as mechanically controlled rigid sails or magnus effect devices.

Procurement of Equipment

Procurement was conducted in accordance with the Asian Development Bank Guidelines for International Shopping for manufacture of the masts, spars, and furling systems. Companies in Australia, New Zealand, United States, United Kingdom, and the Netherlands with established reputations in the manufacture of large spars and sail furling/reefing sytems, were invited to quote and were circulated with specifications and drawings. In the event, only two companies were able to supply the required equipment within the limited time frame of the Project. Of the two, a New Zealand quote was significantly less, and the company had the advantage of being geographically the closest to Fiji with the possibility of after sales service.

Preparation of Vessel

During the design phase, the alterations necessary for the retrofitting of the sail system were discussed with Marine Department officers and shipyard personnel, who prepared detailed costings. This work was completed within budget. However, many other problems not associated with the retrofitting were found. *Na Mata-I-Sau* was due for annual survey and the sail retrofitting work in the shipyard was timed to be coordinated with the survey work. The timing was also planned to allow a sufficient period for sail trials before the end of the trade wind season in October. In the event, it was necessary to extend the survey work, and although retrofitting and annual overhaul were carried out simultaneously, the period available for sail trials was unavoidably delayed and shortened.

Installation of Sailing Rig

The modifications and additions required for the retrofitting, as specified by MacAlister Elliott and Partners, were carried out by the Sailing Master and the shipyard personnel.

Chain plates for the main and mizzen standing rigging were welded to bulkheads and ships frames. All the chain plates were positioned inboard, to prevent damage while the ship was alongside a berth. Sheet and outhaul lead points were positioned and welded to the forecastle, main and after decks, with appropriate stiffening pads. Electric-powered winches for main and mizzen sheets were positioned on strong points and sheet leads arranged. Mast steps were fabricated and supporting structures strengthened to take the additional loading. Masts and spars were shipped from New Zealand and unloaded onto pontoons in Suva Harbour. Masts had been preassembled and then split into half lengths for ease of transport. Booms and the wishbone were shipped complete.

The masts were reassembled by the Sailing Master and a representative of the manufacturers, on the Marine Department jetty alongside the ship. The masts were dressed with running and standing rigging, electrics and instrumentation, before stepping in place. Standing rigging was prespliced to length from MacAlister Elliott and Partners' drawings. Rigging screws were attached for final adjustment and tensioning. The masts were stepped using a mobile crane, the prespliced standing rigging was coupled up to the chain plates and tensioned. Booms and the wishbone were hoisted into position with mast head lines, and finally, the running rigging was rove off.

Shipyard workers fabricated and fitted the exhaust modification to the funnel. This consisted of a cylinder with a flared entrance into which the main engine and generator exhausts are directed. The hot exhaust gas is mixed with cool ambient air in the cylinder which channels the cooled exhaust away from the mizzen sail, thereby preventing damage.

Instrumentation

To conduct the experimental aspect of the Project, all aspects of the ship's performance had to be measured and recorded, so that actual fuel savings could be quantified. Instruments measuring speed, wind condition and fuel flow, were fitted. *Na Mata-I-Sau's* deck officers were regularly measuring and recording the following information while the vessel was at sea:

Reading	Instrument
Ship's speed through water	Log
Distance traveled through water	Log
Latitude and longitude	Satellite navigator
Wind Speed (apparent)	Anemometer
Wind direction (apparent)	Masthead indicator
Engine revolutions	Tachometer
Fuel flow	Flow meter

Readings were noted in a separate, sailing logbook, which was later analyzed to build up a data base from which not only accurate fuel savings can be identified for *Na Mata-I-Sau,* but also predictions for other vessels operating under the sail-motor mode.

SEA TRIALS

Commissioning the Sail Rig

The final stage of the retrofit, commissioning the sailing rig, was carried out by *Na Mata-I-Sau's* officers and crew under the direction of the Sailing Master. The three sails were hoisted up their luff spars, using lead blocks to outhaul winches. The halyard swivels were mounted on an alloy sleeve which fitted on the luff spar and were found to be jamming while hoisting. This problem was solved by leading the halyard standing parts aft so as to put the halyard on the same side of the swivel as the head of the sail. With both forces acting in the same plane, the friction was much reduced, although hoisting the sails still required considerable power as the halyards were single part rovings. Halyards were made fast on mast cleats once the sails were hoisted. The sail could be quickly dropped, but only when fully set.

The furling system doubled as a method of reducing sail area to suit strong wind conditions. The luff spars were rotated by mechanical gear boxes mounted at the lower end, operated manually by a crank handle. In the furled position, the sails were wound around the spar until the clew was only just visible. The area of sail required was set by slacking the gear box on the brake. Unwinding the sail from the spar was achieved by tensioning the clew outhaul on the winch. The tension in the sail, and therefore its member, was adjusted by the clew outhaul pulling against the gear box ratchet. Once set, the clew outhauls were 'stopped' on cam jammers, allowing constant hold during tensioning and quick release for slacking.

To stow the sails, the clew outhauls were slacked over the winch barrels as the gearbox was cranked. With practice, the sails could be swiftly and tightly furled without flogging by maintaining sufficient tension on the clew outhaul to prevent loose sail taking charge.

Two electric powered capstan heads were installed during the retrofit. One was mounted on the after end of the main hatch at waist height, to handle the main sheet. The second capstan head was fitted on the upper deck, on the starboard side of the mizzen mast, and handled the mizzen sheet and the main peak sheet. Both mizzen sheet and main peak sheet were fitted with cam stoppers so that the capstan could be used for either. The jib sheet was handled by the manual sheet winch mounted on the forecastle head which also served the main clew outhaul and the luff spar lines.

The luff spar, being supported at either end, relied on the tension in its core cable for stiffness. To prevent excessive sag in the spar, with detrimental effect on sail-set and efficiency, various intermediate support devices were experimented with. Mechanical systems were found to be insufficiently flexible. Experiments with a length of webbing passed through eyes in the luff of the sail to a block on the mast and then to the forecastle winch proved effective and easy to operate. Two lines were fitted to the main luff spar and one to the mizzen. The lines rolled up in the sail to the furled position and were tensioned at the desired sail-set position from the deck to hold the luff spar into the mast. This system allowed reduced tension in the luff spar cables, thereby reducing strain on the masts.

Crew Complement

Na Mata-I-Sau normally carried a crew complement of 18, as follows: Master, First Mate, Chief Engineer, Second Engineer, Bosun, two greasers, two cooks, two cadets, and seven seamen. *Na Mata-I-Sau* carried a large crew in view of their need to act as stevedores and work boat operators during cargo work at islands with no harbor facilities. Sea watches consisted of one deck officer and two seamen, on four-hour watches.

Crew Activities

The retrofitted sail system was designed for minimum crew input. All sails were normally furled by a maximum of five men in less than five minutes. Once furled, the sails required no further handling until reset, which occupied the same crew input as furling. However, the sailing rig did require adjustment at sea for alterations in course and wind direction, as well as changes in wind velocity. The individual tasks involved in sail adjustment could be effected by one or two men, using the power capstans

installed. To allow for sail adjustment without increasing the work load of the watch on deck, an additional watch roster was drawn up, which designated two men on call for eight hours daily. The normal ship's sea watch duties were increased to provide a forward lookout. Forward visibility from the bridge had been improved by the removal of the foredeck awning but the jib and mainsail obscured a portion of the horizon from the helmsman's view.

Following recommendations by the Consultants, *Na Mata-I-Sau* was the designated training ship for the Marine Department. This role gave the ship an additional two to four cadet officers who stood watches and one who was responsible, under the guidance of the Master, for the keeping of the sailing log. The sailing log, designed by the Consultants, was kept on the bridge in addition to the ship's deck log, and records all the information needed to analyze the sail-motor performance of the ship.

Maiden Voyage

The involvement of Marine Department personnel at all levels in the sail retrofitting and associated work created considerable momentum. The first day of sail trials was viewed with much interest by the whole maritime community at Suva. The maiden voyage was carried out under the command of Captain J. Aisea (Marine Department Fleet Superintendent) with observers from the shipyard on board.

The offshore wind allowed the ship to be maneuvered away from the dock under sail. With main engine turning over as a precaution, *Na Mata-I-Sau* gathered way and reached across Suva Harbour to the reef passage entrance. This demonstration of vessel control under sail provoked recognition from the waterfront in the form of a mass blowing of sirens.The reef passage entrance to Suva harbor required *Na Mata-I-Sau* to be laid close hauled. The Sailing Master advised the Captain to be ready to engage the main engine as the anticipated leeway may have brought the vessel close to the reef on the lee side. However, the vessel did not make the expected leeway and the narrow entrance was negotiated under sail alone.

Once in the open sea, sailing maneuvers of tacking and gybing were carried out. The vessel proved to be well balanced and under the control of the rudder, reaching speeds in excess of six knots under sail alone in apparent wind speeds of 12 to 14 knots. *Na Mata-I-Sau* returned to her berth under sail and final docking was carried out under power. The maiden voyage created great confidence and enthusiasm among the officers and crew.

The extended annual survey work of the ship had delayed the commissioning date by one month, leaving little time for training the crew in the operation of the vessel. The Marine Department schedule required a trip to the island of Rotuma, a distance of 700 km to the north of Suva. This ocean passage was not ideal for the inaugural voyage as the vessel would be away from base for an extended period without facilities for modifications.

Rotuma Voyage

The voyage to Rotuma took 43 hours, giving an average speed of 9.5 knots, and was subject to variable weather owing to the passage of a depression to the south of Fiji. The first part of the passage from Suva to Bligh Water was directly to windward and no sail was set. From the north east corner of Viti Levu, the course lay north west and full sail was set to the easterly wind and engine revolutions were decreased to maintain the normal operating speed for the ship, around nine knots. From the northern exit of Bligh Water, the northerly course to Rotuma brought the vessel close hauled, and engine revolutions were further reduced to maintain nine knots with increased thrust from the sails.

The reduced engine load from motor sailing had several beneficial effects. First, the usual black exhaust smoke disappeared. Second, the engine vibration and noise level was reduced considerably, making the vessel a much improved place to live. Whilst the pressure of wind on the sail rig caused the vessel to heel to a steady angle of about ten degrees, the passengers and crew found the motion greatly improved from the usual motoring attitude of a 15-degree roll both sides of vertical.

During the northern leg of the voyage, the wind increased to 28 knots with the passage of the depression, increasing the ship's speed to 10.5 knots. At this wind speed, the angle of heel increased to 15 degrees and the mainsail was reefed in accordance with standing instructions which had been drawn up for the sail-motor application. With the mainsail reefed to half its area, the ship returned to a heeling angle of ten degrees and maintained a speed of 10.3 knots at significantly reduced engine revolutions.

The torque loading imposed on the luff spar by the reefed mainsail proved too great after some hours of sailing, and the spar fractured at its lower end. The mainsail was then furled and later the wind backed into the north. Mizzen and jib were then also furled, as the course was then directly into the wind. Engine revolutions were increased to maintain nine knots. The Consultants repaired the luff spar at sea by cutting off the fractured part of the spar and replacing the tack fitting on good metal. However, the wind stayed uncharacteristically in the north until arrival at Rotuma and the voyage was completed under power.

On arrival at Rotuma, the cargo of 70 tons of building materials was discharged alongside the wharf, using the ship's mainsail boom as a cargo

derrick. This aluminum spar was one-tenth the weight of the original steel derrick and required considerably less crew effort on the boom guys.

The return cargo of 50 tons of copra was loaded from trucks, also using the boom/derrick and a sundry cargo of fruit, vegetables, and one pig[1] for Suva market was placed on top. The return passage to Suva was completed in 44 hours with variable wind direction and strength, although the mainsail reefing gear fractured for a second time while reefed. Engine revolution reductions were effected while motor sailing under jib and mizzen.

SAILING CHARACTERISTICS

Performance under Pure Sail

Na Mata-I-Sau's performance under pure sail proved better than expected. At the design stage there were anxieties over the relatively flat bottom hull shape and consequent leeway, and the small size of the motor ship's rudder. Although there was relatively little time spent under pure sail, early results were encouraging. On all points of sail, the vessel remained in control of the rudder with small rudder angles. At speeds above three knots, wearing ship and going about were accomplished without engine. *Na Mata-I-Sau* would sail at about 50 degrees to the apparent wind with little evident leeway. With about 300 tons of ship, accelerations were very slow and it could take several minutes to reach cruising speed. The vessel would steady to a heel angle and was largely unaffected by small wind fluctuations. The strain on the rigging from sudden gusts could be very high. When the main engine and generator were both shut down, a calm, not appreciated since the days of sail, would descend on the ship.

Motor Sailing

Na Mata-I-Sau's function in the Marine Department fleet was to carry cargo and passengers between the capital, Suva, and the other islands of Fiji. Until the implementation of the sail-motor project, the ship had carried out this function at a service speed of about 8.5 knots. The reorganization of the ship's ballast system and removal of unnecessary sullage in the aft tanks improved the trim of the vessel so that she no longer excessively trimmed by the stern. The removal of the stern post and fairing in of the rudder blade increased propeller efficiency, so that on motor trials with a clean bottom, the ship's speed increased to 10.2 knots at full power.

1 The pig was very seasick.

For normal passage making, maintaining a minimum service speed of eight knots was considered desirable. Thus, the apparent wind angle to the sails is drawn further forward than for a vessel operating under sail alone. Use of power in combination with sail creates a headwind which converts a reach to a close reach and a close reach into close hauled. Broad reaching and running become of little value to the vessel unless the wind is strong, as the effective wind is reduced by the equivalent forward speed.

Motor-sailing a ship requires a different technique and an appreciation of the forces involved. The forces required to propel a 300-ton vessel at nine knots in a seaway are very large and perhaps only 25 per cent of the thrust comes from the sails. Consequently, the ship is not responding only to wind forces, and large changes in rig stress may show little evidence on the ship. The Officer of the Watch, therefore, must be aware of wind shifts from the instruments and must not hesitate to reduce sail at the prescribed levels. For the same reasons, incorrect sail trim is not immediately apparent through loss of propulsion. Nevertheless, even at high engine power, the stabilizing effect of the sails is dramatic and everyone on board is aware of the lift being given to the ship by the wind.

In the operation of *Na Mata-I-Sau,* the only variable which could be controlled was the engine revolutions. Fuel savings were effected by reducing engine revolutions as power became available from the sail rig to maintain a predesignated service speed. Further savings were made when, for example, forward planning showed the vessel's arrival time at an island location to be after dark, when cargo handling was impossible. In this case, the main engine power could be further reduced and the vessel operated under sail so as to arrive with the first daylight and start of the working day. As observed during sailing trials, the operation of the vessel under sail was considerably more comfortable in both motion and noise level terms, putting less strain on both passengers and crew.

CARGO HANDLING

Na Mata-I-Sau carried general cargo, often bagged copra, which used to be loaded and discharged using a welded steel tube derrick supported from a stub mast stepped on the main deck and reinforced by the forecastle bulkhead. The electric cargo winch was mounted at the foot of the mast. The sail system designed by MacAlister Elliott and Partners used the original mast, shortened to forecastle deck height, on which to stand the main mast. The lower section of the main mast was strengthened to take the derrick block loads. The aluminum mainsail boom replaced the original welded steel tube and was of the same dimensions, using the original gooseneck still mounted on the lower steel mast.

To handle cargo, the mainsail clew outhaul and main sheet block were cast off from the boom end. The derrick gin block was cast off from the port rail and shackled to the top eye on the boom, and the boom guys uncoiled and shackled to the side eyes. The boom topping lifts used for sailing were left on the boom end and the cargo topping lift of 14 mm wire, permanently rove off through the gin block, was set up, lifting the boom into its cargo operation position. The lower gin block through which the lifting wire runs to its hook, was shackled on the under side, opposite the topping lift gin block.

The new system was quicker to set up than the original and involved less physical effort. The operation of cargo movement was also judged an improvement by the ship's crew, as the new boom was considered easier to swing, owing to its low weight. The furled sail had no effect on the operation of cargo handling, the two parts of the topping lift passing either side of the roll of sail to their hinged mast brackets (see Plate 2).

The cargo handling system was tested during commissioning of the vessel by fastening a calibrated ten-ton tension meter between a strong point on the deck and the cargo hook to the top of the strain meter. The cargo winch was then operated until, at a constant strain of 3.5 tons, the deck strong point welding failed. The gantry was rated at a safe working load of 1.5 tons.

EXPERIMENTAL TESTING AND DATA COLLECTION

The aim of the project was to monitor the *Na Mata-I-Sau* during the course of her normal duties. However, in order to evaluate the sailing potential of the vessel, a number of tests were carried out to establish basic ship data.

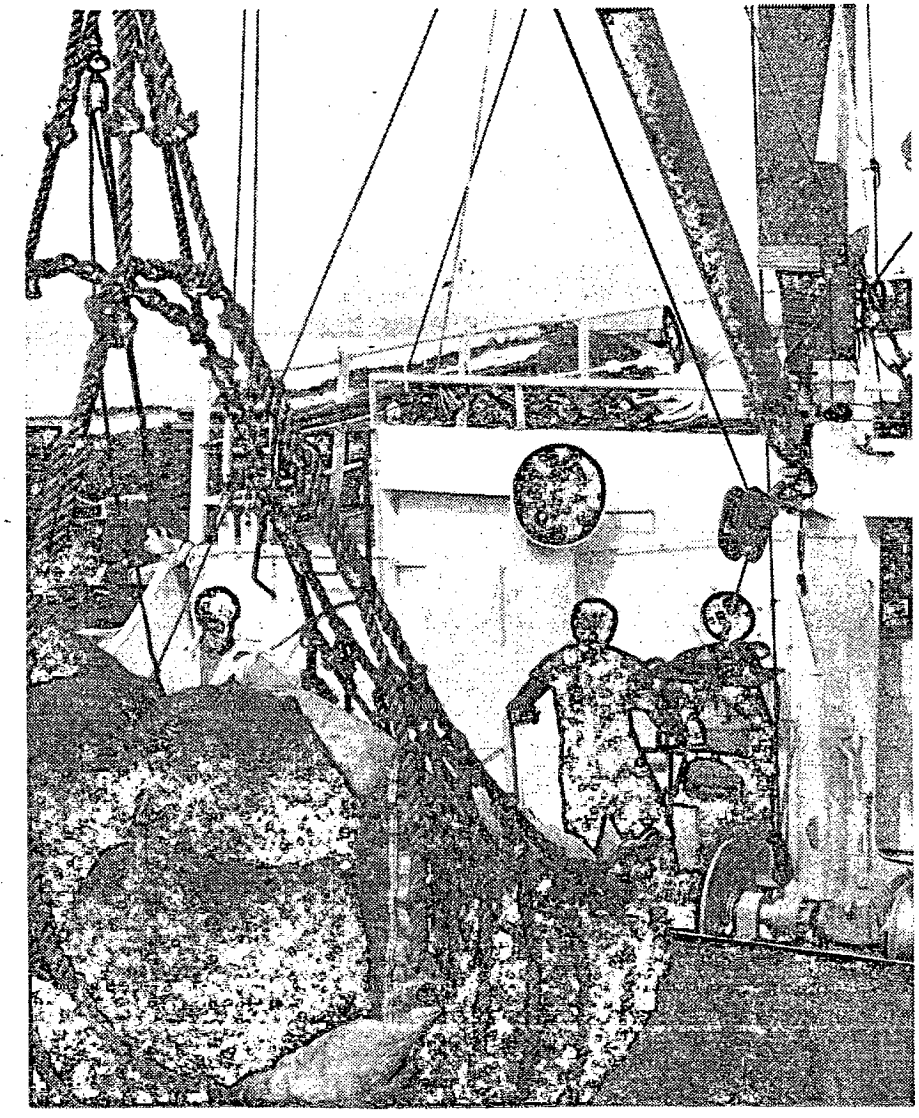
Free Running Tests

After calibration of the instrumentation, free running tests were carried out to record the performance of the vessel under power only. These were run on various reciprocal courses in calm conditions in Suva Harbour. Runs were made at fixed engine speeds between 700 and 1,650 revolutions per minute (rpm). Ship speed, fuel consumption, wind speed and direction, were recorded on each occasion.

Straight Towing Tests

Straight towing tests were carried out to measure ship upright resistance at a variety of speeds. A calibrated ten-ton tension meter was mounted on

Plate 2



The mainsail cargo boom doubles as an efficient cargo derrick for lifting 1.5 ton loads of copra and other cargo. The mainsail is shown neatly furled against the mast clear of cargo operations.

Na Mata-I-Sau, attached to a 200-meter nylon hawser. First tests were carried out with a 350 horsepower (hp) tug towing *Na Mata-I-Sau* in Suva Harbour. However, this was insufficient power to record more than seven knots. An 1,125 hp tug, the largest in Fiji, was chartered and further tests carried out in light winds. Over reciprocal courses, hawser tension, ship speed and wind speed and direction were recorded with the engine in neutral. Maximum speed achieved was 8.8 knots, limited by the hull speed of the tug.

Tests at sea take a long time. The vessels were in radio contact but setting conditions and waiting for readings to stabilize was a lengthy process. Nevertheless, reasonably repeatable results were obtained over the speed range of 5.5 knots to 8.8 knots. Some readings were taken with *Na Mata-I-Sau's* engines going ahead at low revolutions. These latter conditions were very difficult to stabilize.

Induced Drag Tests

A sailing vessel is subjected to side loads from wind forces, the resulting thrust acting about amidships. To resist this, the hull must make leeway and lift to windward. This causes induced drag in addition to upright resistance; in other words, increased forward resistance due to the vessel being blown sideways. To quantify this drag, a series of induced drag tests were attempted.

The tension meter was mounted amidships and the hawser fed through an amidships freeing port to the tug. In this way, by pulling at an angle to *Na Mata-I-Sau,* the tug could simulate the resultant wind force vectors. Readings were taken of tension, hawser angle to ships heading, ship speed, wind speed and direction, and rudder angle. We attempted to measure leeway using towed and visual methods. Leeway proved highly variable but in any case, it was not more than a few degrees. The induced drag tests proved difficult to conduct as small changes in heading produced large changes in relative position. *Na Mata-I-Sau* had a surprising tendency to overtake the tug. Even with tow angles as high as 80 degrees to the ships head, leeway was very small and forward speed was maintained. At these high angles, the 1,125 hp tug was having difficulty maintaining steerage. Nevertheless, a number of readings were taken for conditions which had been stable for 60 seconds or more, based on set tug engine speeds. This gave readings at ship speeds between 6.5 knots and 8.6 knots and tow angles between 15 degrees and 85 degrees. The high angle readings tended to be unreliable due to the hawser bouncing sideways through the waves.

A further inclination test was carried out on *Na Mata-I-Sau* after the masts were installed and the ballast system overhauled. The original steel derrick structure and some awning supports and cabin bulkheads had been removed in the retrofit. The vessel now trimmed more evenly and displaced less in the ballasted condition.

In spite of the addition of the masts and rigging, she proved to be stiffer with the metacentric height increasing from 0.397 metres to 0.492 metres. Although there are no stability criteria laid down by the Fiji Government, the hydrostatic and stability computer analysis, carried out in the United Kingdom showed that *Na Mata-I-Sau* complied with International Maritime Organization (IMO) and United Kingdom Department of Trade and Industry requirements.

Sail and Motor/Sail Trials

To achieve a wide variety of readings in the relatively short time available, the Consultants spent a number of days on sailing and motor sailing tests in various directions and prevailing conditions. This was in addition to records made during normal vessel operation, mainly the 1,400 km round trip to Rotuma.

The only variable which could be set in any of these tests was engine rpm. All other readings were taken once conditions had stabilized. Accelerations were very slow under pure sail and sometimes it took many minutes before conditions became steady. Readings were taken for a wide variety of wind directions and strengths. The following parameters were recorded: trim, ship speed, engine rpm, fuel flow, apparent wind speed and direction, angle of heel and sail area.

ECONOMIC ANALYSIS

Net Benefits

Following analysis of the data collected in the sea trials and experimental testing, the economic net benefits were measured for use of sail on the *Na Mata-I-Sau.* The 'do nothing' case is determined as the continuation of present practices. The only benefits considered in the calculations were those of fuel savings. There were other unquantifiable benefits in the form of:

(i) Ship steadiness at sea, which made the passage more agreeable to passengers and crew;

(ii) Availability of a secondary form of propulsion in case of engine failure, which was considered particularly important in the coral reef studded waters of the Fiji archipelago; and

(iii) The pride taken in their ship by the Government's seamen in exercising their skills as sailors.

Disadvantages of Sail

The disadvantages of using sail were less obvious. The additional work of setting and controlling the sail was not great, even in strong winds because of the roller reefing gear and the simple sail plan. The crew numbers are defined by the requirements for cargo handling with the ship's boats and there is no shortage of available personnel. In any event, the jib and mizzen can be furled single handed in normal conditions and the main by three crew. Even if there are only three or four deckhands on board, the gear for handling the sails is so simple that there would be no difficulty in sail management. The performance of the ship at cruising speeds between seven and ten knots was impressive, and so voyages did not take longer than when only using engines.

If slower speeds are acceptable, then substantial additional fuel savings can be made by stopping the engines for significant periods of a voyage and proceeding under sail only. There seems, therefore, at this stage of the experiment, to be no major disbenefits. There seems little opportunity for development of an indigenous sail-making activity in Fiji as the result of retrofitting sails. However, the existing yacht-oriented sail maintenance and repair lofts in Fiji would benefit from an increase in work.

To convert the financial costs into resource or economic costs, it is normal practice to remove import tariffs, taxes, subsidies, monopoly profits and 'protected' wages at higher than market rates. It appears to be the practice in Fiji to assess the resource cost of skilled labor at the market rate. The use of unskilled labor is relatively low. The costs of imported materials are those free on board plus the cost transport from the overseas port. No import duties or taxes were raised on the materials for the Project.

Fuel Saving Percentages

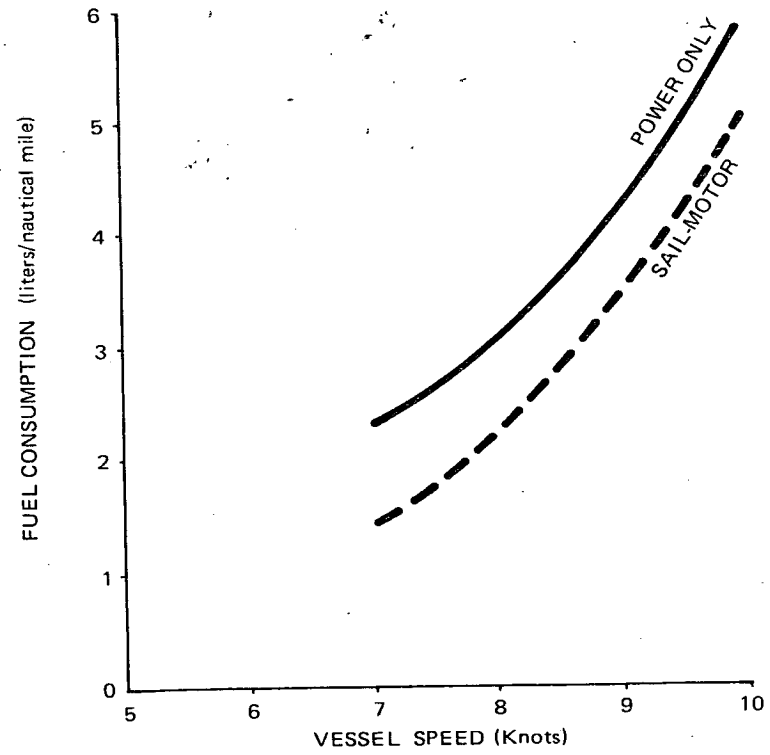
Fuel saving was based both on actual measured values from sea trials as shown in Table 2 and on the theoretical savings predicted by the Southampton model shown in Figure 2. The theoretical model gives average direction fuel savings of about:

- 16 per cent at nine to ten knots;
- 23 per cent at eight to nine knots; and
- 34 per cent at seven to eight knots.

The sea trials figures were recorded, obviously, on courses where motor-sailing was possible and do not represent an average of all directions.

Figure 2

Fuel Consumption vs Vessel Speed
(FOR ASSUMED FUEL CONSUMPTION AND PROPULSIVE EFFICIENCY)



(1) Curves are based on assumed propulsive efficiencies and engine fuel flow. Measured fuel flows may be representative of sail-motor, in which case the fuel consumption (Y) axis should be scaled by a factor of around two.

(2) The fuel-equivalent of sail power is based on annual average winds.

However, the Southampton relative fuel saving curve, Figure 3, enables a comparison to be made between the theoretical percentages and actual values relative to prevailing wind directions. A fuel saving of 23 per cent at between eight and nine knots reflects the benefits which are reasonable to adopt as an average.

The measured fuel consumption of *Na Mata-I-Sau* is greater than the figures deduced from the model used for the calculation of the fuel savings. This needs further investigation, as such a situation could mean an underestimation of net benefits from the sail retrofit experiment. The higher fuel consumption may be the result of inadequate maintenance or improper use of machinery and this may be typical of vessels in this kind of service. Should the propulsive efficiency be improved, the absolute fuel consumption will fall, but as part load efficiency will also increase, the fuel savings due to sail will be maintained.

The fuel oil is purchased by the Government and is not subject to tax. The purchase price in 1983 was F$0.3798 per liter in bulk and F$0.5002 in drums. This year (1985), the price has increased to F$0.4098 per litre for fuel oil in bulk. Because of the past trend of increases in the factor cost of fuel, a figure of 3.3 per cent has been adopted over the appraisal period in keeping with the World Bank's recent modest estimates of likely increases. The results have also been subjected to a sensitivity test without this percentage increase.

Figure 4 shows the main courses and distances in nautical miles to the outer islands from Suva. The compass rose shows the favorability of the courses for sailing. Obviously, the largest fuel savings can be gained on the most favorable routes. If *Na Mata-I-Sau* and one other vessel were used on the routes which will give the greatest savings, they could undertake the 20 voyages considered to be required annually to Rotuma, the 50 voyages to Koro, and the 50 voyages to Taveuni. This gives an overall saving, weighted for 120 voyage days to Rotuma and 400 to Koro and Taveuni, of 33.02 per cent.

The factors for reduced fuel consumption with prevailing winds derived from the model on the courses where the benefits are greatest, are set out in Table 2. The factors for other destinations in Fiji are recorded in Table 3.

Table 2
Factors for Reduced Fuel Consumption

Destination	Rotuma	Koro	Taveuni
Voyages/year	20	50	50
Fuel consumption:			
outward voyage	1.55	1.31	1.31
homeward voyage	1.03	1.64	1.64
Days spent on these voyages including loading and discharging	170	200	200

These voyages could be provided by *Na Mata-I-Sau* and one other retrofitted vessel.

If six or seven other vessels were retrofitted, the 500 voyages to the other outer islands could be provided. These 'average' voyages, predominantly on east to west courses, would have a 'reduced fuel factor' of 1.24 on one leg and 0.20 on the other.

Table 3
Factors for Other Destinations

Destination	Lautoka	Kadavu Gau	Cicia Vanua Balavu	Kabara Moala	Lakeba
Voyages	100	200	100	50	50
Factors for reduced fuel consumption:					
outward voyage	1.24	0.20	0.20	0.20	0.20
homeward voyage	0.20	1.24	1.24	1.24	1.24
Days spent on these voyages including cargo operations	300	600	400	200	200

Figure 3

Relative Fuel Savings vs Course Sailed

RELATIVE FUEL SAVING IS THE FUEL SAVED ON A VOYAGE IN A SPECIFIED DIRECTION DIVIDED BY AN AVERAGE FUEL SAVING REPRESENTATIVE OF VOYAGES IN A RANDOM DIRECTION

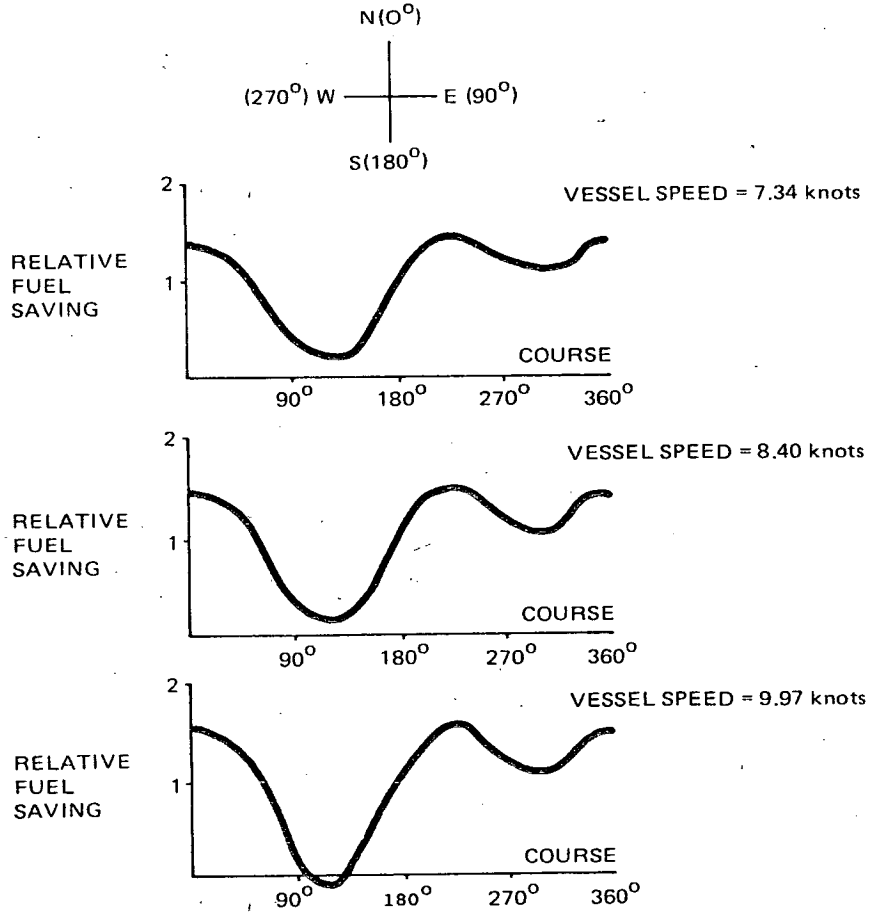
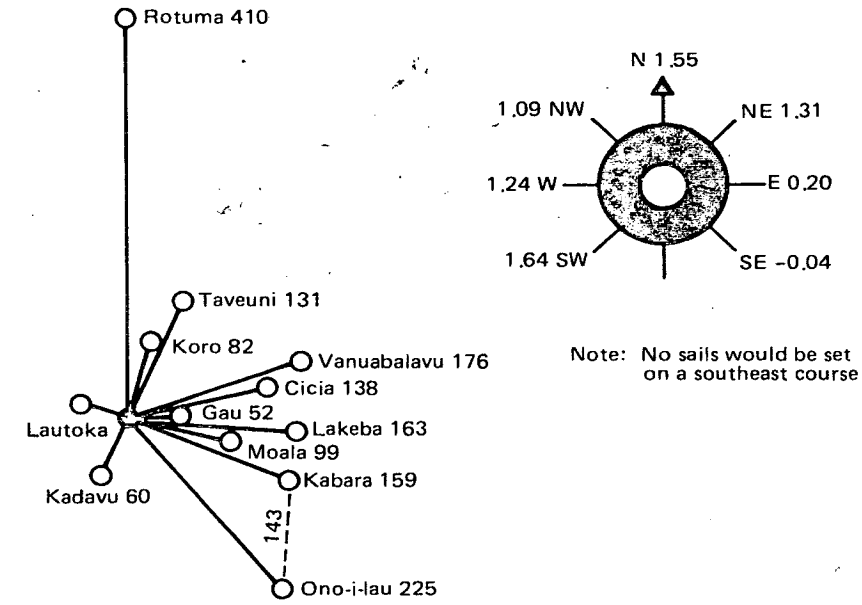


Figure 4

Angles of Sailing and Factors for Reduced Fuel Consumption with Prevailing Winds in Fijian Waters



Note: No sails would be set on a southeast course

Distances in Nautical Miles

		Voyages per year	Predominant course	Reduced fuel factor out	Reduced fuel factor home
To	Lautoka	100	W	1.24	0.20
	Rotuma	20	N	1.55	1.03
	Kadavu	100	E	0.20	1.24
	Gau	100	E	0.20	1.24
	Cicia	50	E	0.20	1.24
	Vanuabalavu	50	E	0.20	1.24
	Kabara	25	E	0.20	1.24
	Ono-i-lau	25	SE	–	1.09
	Moala	25	E	0.20	1.24
	Koro	50	NE	1.31	1.64
	Taveuni	50	NE	1.31	1.64
	Lakeba	50	E	0.20	1.24
		645			

For Ono-i-Lau, when sailing south east, sails would rarely be used because of the predominant head winds. A north west course would be before the wind and this has been determined to be an unsatisfactory point of sailing with power unless winds are strong.

The average percentage fuel reduction for Rotuma from the use of sails on the 'best' courses, at speeds between eight and nine knots, based on the conclusions from the Southampton model, is:

$$\frac{(1.55 + 1.03)}{2} = 1.29 \times 23\ \% = 29.67\ \%$$

and for Koro and Taveuni:

$$\frac{(1.31 + 1.64)}{2} = 1.48 \times 23\ \% = 34.04\ \%$$

Average Course Fuel Savings

The average percentage of fuel reduction from the use of sails on the 'average' course is:

$$\frac{(1.24 + 0.20)}{2} = 0.72 = 16.56\ \%$$

With higher speeds of between 9 and 19 knots, the savings are likely to fall, giving a saving of 23 per cent on the best courses and 11.5 per cent on the average courses. At lower speeds of between seven and eight knots, the savings are likely to increase to 49 per cent on the 'best' courses and 24.5 per cent on 'average' courses. The fuel consumption per nautical mile will vary at different speeds. The annual fuel cost for operating at nine to ten knots has been increased by 20 per cent for the economic rate of return calculation. Similarly, the fuel costs have been reduced by 20 per cent for the seven to eight knot calculation.

Annual Fuel Cost

Annual cost of fuel and oil for the vessels *Na Mata-I-Sau* and *Tabu Soro* were F$53,495 and F$55,954, respectively, at an annual average speed of eight to nine knots. An increased vessel utilization of a modest ten per cent, to provide services on the 'best' courses, would give totals of F$58,844 and F$61,549, respectively. Average consumption of fuel per vessel would cost F$60,197. On the 'best' courses at eight to nine knots, therefore, the fuel saved would be F$24,079 per annum, and on the 'average' courses about half of this saving.

Retrofitting Cost and Maintenance

Out of the retrofit budget of US$40,000, the cost of masts, spars, sails, rigging equipment and fitting, was F$36,000. The balance was used for instrumentation and other equipment. It is estimated that annual maintenance would cost F$2,000 and that in every fourth year, this would rise to F$10,000, to include a new suit of sails. A refit is provided for every eighth year. Once the system is tested, the retrofitting need only take a short time in the Government dockyard.

Economic Rate of Return

The net economic rate of return calculations are shown in Table 4. At a reasonable cruising speed of eight to nine knots, the estimated Economic Internal Rate of Return (EIRR) varies from an impressive 123 per cent on the 'best' courses to 30 per cent on the 'average' courses or 23 per cent for the latter if there is no increase in the real cost of fuel.

These fuel cost corrections comply generally with the measured consumptions in the sea trials but are less than those predicted by the Southampton model.

As speed increases under sail, percentage fuel savings drop but fuel consumption increases. Thus, absolute fuel savings and EIRR remains good, but at higher total running costs.

Pure Sail

None of these results take any account of the potential for using pure sail. In any developing world shipping operation, schedules will be affected by daylight, shore facilities, tides, etc., as well as passage time. There will be many occasions when a lower passage speed will be operationally acceptable.

Reasonable speeds can be maintained under pure sail in almost half of all wind directions. Bearing in mind the reduction in ship noise and vibration, it is reasonable to assume that pure sail will be used some of the time.

This, of course, has a marked effect on the economic benefits. For instance, if the eight-to nine-knot ship on the average course were to pure

Table 4
Net Economic Benefits from Sail-Assistance

Year	Vessel Retro-fitting Cost F$	(a) Best Course Fuel Saved F$	(a) Best Course Net Benefit F$	(b) Average Course Fuel Saved F$	(b) Average Course Net Benefit F$	(c) Without increased real cost of fuel in (b) Fuel Saved F$	(c) Without increased real cost of fuel in (b) Net Benefit F$
1	36000	2039	(15605)	9969	(26031)	9969	26031
2	2000	21068	19068	10298	8298	9969	7969
3	2000	21763	19763	10638	8638	9969	7969
4	2000	22481	20481	10898	8989	9969	7969
5	10000	23223	13223	11351	1351	9969	(31)
6	2000	23989	21989	11726	9726	9969	7969
7	2000	24781	22781	1213	10113	9969	7969
8	2000	25598	236598	13513	10513	9969	7969
9	20000	26444	6444	12925	(7075)	9969	(10031)
10	2000	27316	25316	13352	11352	9969	7969
11	2000	28218	26218	13793	11793	9969	7969
12	2000	29149	27149	14248	12248	9969	7969
13	10000	30111	20111	14718	4718	9969	(31)
14	2000	31104	29104	14204	13204	9969	7969
15	2000	32131	30131	15705	13705	9969	7969
16	2000	33191	31191	16224	14224	9969	7969
17	20000	34286	14286	16759	(3421)	9969	(10031)
18	2000	35418	33418	17312	15312	9969	7969
19	2000	36587	34587	17884	15884	9969	7969
20	2000	37794	35794	18474	16474	9969	7969

Ship Speed			F$	F$	F$
7/8 knots	Est. EIRR		180.23%	40.58%	33.76%
	net present value (%)	8	239180	80390	45760
		10	203160	65420	37350
		12	174570	53570	30550
8/9 knots	Est. EIRR		123.16%	29.78%	22.65%
	net present value (%)	8	196999	55748	26464
		10	166572	44040	20301
		12	14238	34792	15323
9/10 knots	Est. EIRR		78.02%	20.89%	13.09%
	net present value (%)	8	145540	33300	9000
		10	121930	24580	4880
		12	103220	17710	1540

sail for 10 per cent of the time, the EIRR would nearly double, even allowing for the fact that the 10 per cent sailing time would probably use the most favourable winds, thereby depressing the average percentage fuel saving for the motor-sailing. The resultant EIRR is shown graphically in Figure 5.

RESULTS OF THE STUDY

Sets of readings were taken for about 50 different sailing and sail-motor conditions, as well as a large amount of data recorded during the experimental testing.

Sail-Motor Data

Results for sail-motor and pure sail are difficult to display graphically as there are always more than two variables, and practical considerations make it impossible to fix any parameters during data collection, apart from engine revolutions. Instead, readings were taken when prevailing conditions became steady with only the general intent of the test being controlled. The performance of *Na Mata-I-Sau* can be represented on a series of curves or surfaces but this requires a very large amount of data which are not yet available. However, operational data will continue to be collected by the crew for at least the next full year.

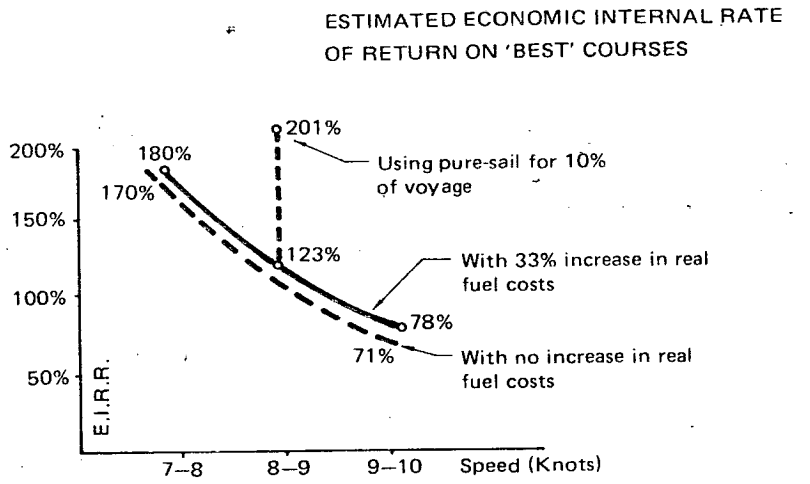
Na Mata-I-Sau handled much better than expected as a sailing vessel and her performance compared closely with the initial calculations on resistance, sail area, stiffness, heel angles and balance.

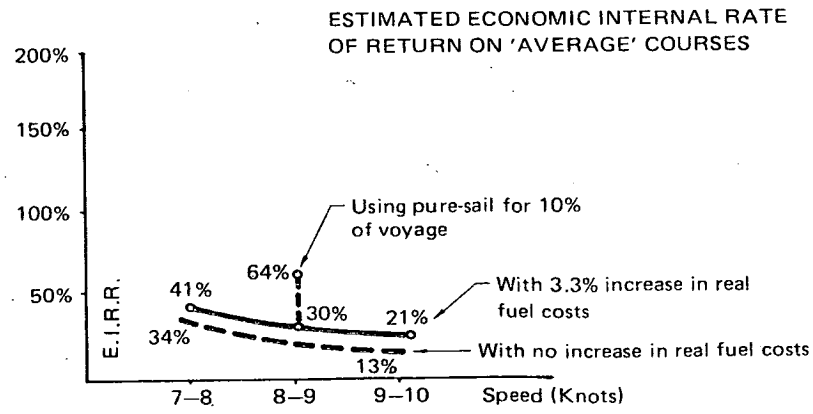
During the planning of the Project, the Consultants were concerned about the small size of the rudder and the lack of any keel-like appendages on the hull. Although it was felt that *Na Mata-I-Sau* would motor-sail in reasonable control, it was feared that, under pure sail, leeway and rudder angle might be excessive and sail reductions might be necessary to balance steerage.

None of these fears proved true. The ship was remarkably well balanced under sail and rudder angles seldom exceeded five degrees. Leeway was small and the heel angle, at about ten degrees when reefing starts, was much easier to accommodate than the normal rolling of the ship. *Na Mata-I-Sau* could sail at 50 degrees to the apparent wind and motor-sail slightly closer. Going about or wearing ship under sail was a controlled if stately process, although some engine assistance might be required in very light airs.

Figure 5

Sail Assistance for Motor Vessels
Net Return in Fiji Waters





Rig Performance

The rig proved easy to handle, with no operation requiring manual strength except the mainsail furling gear box, which was subsequently changed. Basically, all the hardware used was well proven equipment and the only gear failure was the mainsail luff spar for which the enormous torque required to hold the sail in reefed positions had been underestimated. Temporary repairs were carried out enabling testing to continue, but time was inevitably lost. The manufacturers have now supplied a new mainsail furling system of adequately massive proportions.

The novel idea of a wishbone yard on the quadrilateral mainsail, enabling the sail to furl vertically within the wishbone, worked well, though some practice was necessary to ensure a neat furl. The wishbone enabled the mainsail to be controlled and shaped easily and provided some remarkable tall flat reefed sail options.

The design philosophy was to reduce sail handling to a minimum and the full significance of this became clear during the tests. Setting, furling, and reefing the sails proved to be quick and easy.

Na Mata-I-Sau was taken out one Sunday with a scratch crew for a photographic session. While returning to her berth, the crew of five on deck furled 225 square meters of sail in less than five minutes.

Other important benefits also became apparent when the cargo deck carried passengers who were protected by an awning. The mainsail could be set, trimmed and furled, without inconveniencing the passengers and, indeed, without them being aware of the activities.

Stowage of Sails

Perhaps the most significant benefit was that the system stowed the sails as well as handled them, as a result of the furling apparatus. During rig modifications when the sails were dropped on deck, their large size and weight became apparent, as did the enormous amount of room required. The mainsail filled most of the cargo deck and it was difficult to see how such sails could be handled on a ship without large areas of the deck specifically set aside. Sail wear was also not a problem, since most sail wear occurs through flogging, ultraviolet sun rays, and crude handling and stowage. All these causes were at a minimum on *Na Mata-I-Sau* as a result of the roller furl system and ultraviolet protective strip on the sail edges (see Plate 1).

Crew Response

The simplicity of the sail handling and the agreeable and safe nature of the tasks involved, resulted in a ready response from the crew. While it is appreciated that the people of Fiji are naturally receptive and that enthusiasm was generated by the Project activities, the Project demonstrated that a regular merchant marine crew would operate a properly designed sail system with pleasure rather than resentment.

Technical Analysis

The base line and operational data collected by the Project allowed various technical and economic analyses to be carried out.

The purposes of these analyses were to:

(i) quantify the ship performance coefficient;

(ii) compare actual performance with performance computed by current theory;

(iii) outline potential further improvements from modifications not included in the Project; and

(iv) analyze the cost effectiveness of retrofitted sail to the Fiji Government fleet as a whole.

Under the Project, the retrofitting of sail to an existing interisland motor ship was successfully implemented and the fact that *Na Mata-I-Sau* and her machinery were far from new caused some problems with theoretical analysis, there being a signficant difference between the theoretical motor ship performance as predicted by Southampton University and the 'as found' performance.

Propulsive Efficiency

Essentially, the propulsion equation can be approached from either end. Measured fuel flow and specific fuel consumption, or engine revolutions and the engine output curves, will indicate the horse power provided. Ship resistance and efficiencies will indicate the horse power which should be needed. At present, these two estimates are a long way apart and the reasons for this are not well understood. Propulsive efficiency appears to drop at lower speeds and the main engine is already using more fuel than specified.

The economic analysis used only measured fuel savings and the EIRRs are based on conservative, average, motor-sail performance, as recorded at sea. Any variation in these figures towards the theoretical model will always increase the absolute and relative fuel savings.

It is also significant that careful instrumentation and detailed towing and performance testing on a small, elderly vessel such as *Na Mata-I-Sau* is probably unique and that the engine manufacturers have little experience from sophisticated fuel metering devices on in-situ engines after long service.

Technical Results

The sea trials under pure sail, together with the measured ship resistance data, enabled Southampton University to improve their mathematical model and to demonstrate the validity of linearized sail theory. While their curve of speed ratio against wind angle is clearly only approximate, based on the limited readings to date, it can be used as the basis for polar sail performance plots such as shown in Figure 6. These show a useful sailing ability from about 65 degrees to the true wind round to about 155 degrees from the true wind. In other words, if a reduction in speed was accepted, *Na Mata-I-Sau* could sail without engine on 50 per cent of all courses in average winds. Furthermore, the vessel could sail without engine most of the time if route planning took account of wind directions.

The economic analysis was approached in a number of ways and the assumptions for the conservative base figures have been explained. It teaches us some very old lessons. Historically, most of the world's trading patterns and, indeed the growth of many civilizations, depended on prevailing wind directions. The economic analysis shows the importance of analyzing fleet operations in terms of average winds, and building or retrofitting ships with auxiliary sail for routes showing the most benefit. The scale of benefits and rates of return in the context of small ship fleets, cannot be ignored.

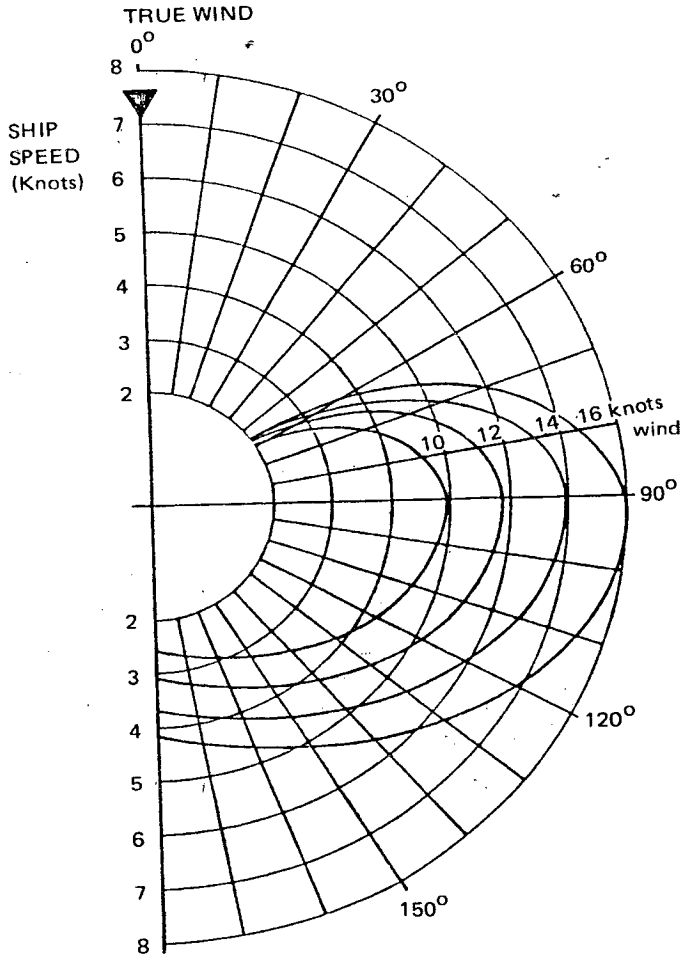
Importance to Developing Countries

In Fiji, the rates of return for the most favorable routes were excellent. Even for all other routes except the least favorable run to Ono-i-Lau, there was an EIRR of 20 to 40 per cent. Time will tell how much these figures will be improved by the use of pure sail on favorable occasions.

With the small capital investments involved, well within the powers of many developing countries or individual shipowners, these results are important and all similar fleets are advised to be cognizant of their potential for auxiliary sail. Certainly, no new vessels or fleet expansion should be contemplated without carrying out an economic analysis of the potential for sail assistance.

Figure 6

Sail Performance



The Project could not fully explore the effects of part load running on the main engine. The General Motors (GM) Detroit diesel engine was not good at light load running. On passage, however, the tendency seemed to be either to shut the engine down altogether or to apply more than half power to maintain a high cruising speed. More than half power is an acceptable engine condition.

Under pure sail, the spinning propeller shaft may cause gearbox lubrication problems but the shaft appears not to rotate until about six knots and the gearbox is being closely monitored.

The Project also showed up the extraordinary fuel inefficiency of the average small ship in service, both from a propulsive and operational viewpoint.

RETROFITTING THE CAGIDONU

In January 1985, the *Na Mata-I-Sau* foundered on a reef with the loss of two crew members in tropical cyclone 'Eric'. While on a voyage from Suva to the Lau Group, with the Prime Minister of Fiji and his party plus a full complement of passengers and crew on board, the single main engine failed. The crew managed to sail *Na Mata-I-Sau* to the reef-fringed island of Moala, which lay some miles to windward. By the time the passengers had been put ashore in the ship's boats, hurricane Eric was imminent and despite all efforts by the crew, *Na Mata-I-Sau* foundered at the height of the storm when she rolled off the reef where she had grounded, into 20 meters of water, and two crew members trapped inside the vessel were drowned.

Christopher Temple, a Consultant team member from MacAlister Elliot and Partners was among the survivors and gave evidence at the subsequent enquiry into the loss of the vessel. The Marine Board Enquiry acknowledged that the auxiliary sail had enabled the vessel to make her way to land, probably preventing the loss of all passengers and crew at sea. In the Marine Board's view, without any means of control the vessel would have almost certainly foundered in such a storm.

The Fiji Marine Department agreed to have the spars and rigging salvaged from *Na Mata-I-Sau,* although the hull itself was considered a constructive total loss. The Sailing Master supervised the salvage operation and the masts, rigging and equipment were brought back to Suva, cleaned and stored.

The fuel savings demonstrated by the experimental rig on *Na Mata-I-Sau* and the demonstration of vessel safety, prompted the Fiji Marine Department to set aside F$50,000 for the conversion of another Government vessel, the *Cagidonu,* to auxiliary sail. This vessel, of 338 grt, was

designed and built in 1978 by the Fiji Government Shipyard as an auxiliary sailing vessel, with a Bermudan schooner rig. However, her masts and spars were built out of 10 mm steel plate and were excessively heavy. This had the joint disadvantage of reducing the vessel's stability and making the gear very cumbersome. The rig was traditional, with all sails raised, lowered, reefed and stowed by hand, which caused an unacceptable work load for the crew. The result of these and other teething problems was that *Cagidonu* operated as a motor ship until 1985 when, due to deteoriation of the standing rigging, the masts were cut off.

The Asian Development Bank agreed to make use of remaining funds from the original technical assistance primarily to meet consultancy costs, while the Fiji Marine Department budget of F$50,000 would be used for further hardware purchases and conversion work.

Accordingly, in July 1985, a team from MacAlister Elliott and Partners visited Fiji to assess the feasibility of fitting auxiliary sail to *Cagidonu* using components salvaged from *Na Mata-I-Sau*.

Cagidonu was found with the original steel masts and rigging cut down to short stumps for cargo derrick support only. An inclining experiment was carried out on the vessel, with the attendance of Mr. Per Gudmunseth, an IMO naval architect on secondment to the Fiji Government Shipyard, to the satisfaction of the Fiji Marine Department. The results were taken back to the United Kingdom to produce a stability booklet.

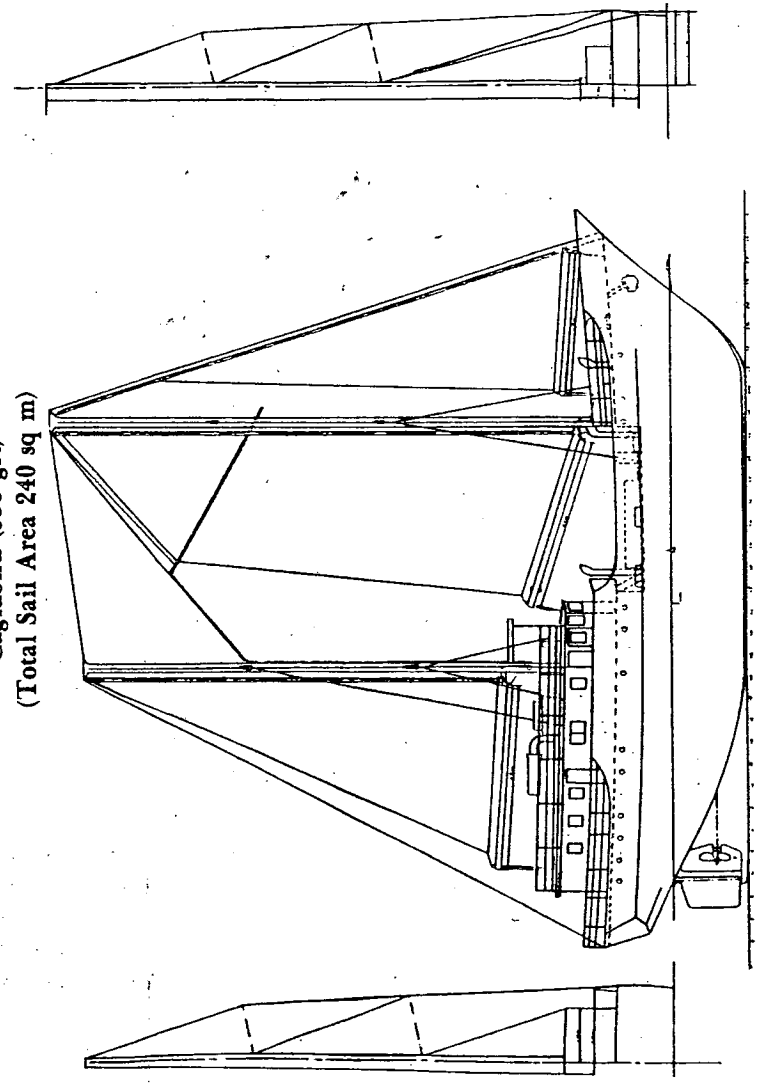
The booklet shows that in all conditions, *Cagidonu* has adequate stability and complies with IMO requirements. With the number two and three ballast tanks full, the worst light ship condition shows that the vessel will heel to 12 degrees in 18 to 19 knots of wind with the proposed rig sail. Stability continues to increase up to about 55 degrees of heel, equivalent to a force ten gale, without any reduction in sail area.

The rig for *Cagidonu* was drawn up, using as far as possible, components salvaged from *Na Mata-I-Sau*. As *Cagidonu* is a larger vessel (338 grt compared to 274 grt) it was necessary to increase the total sail area. The salvaged main mast has been extended by three metres in length and the salvaged mizzen boom is being used as the jib boom. With a new mizzen mast and boom, this gives a total sail area of 240 sq m as opposed to 201 sq m for *Na Mata-I-Sau* (see Figure 7).

At this time, the *Cagidonu* retrofit is almost finished and it is expected that sailing trials and data collection will be under way soon[1].

1 Subsequent sail trials for *Cagidonu* since presentation of this paper were entirely successful, with similar fuel saving and other benefits experienced as for *Na Mata-I-Sau*. *Cagidonu* is now operating with sail assistance under the control of her regular crew, on normal fleet operations.

Figure 7



The Second Sail-Retrofit Vessel
Cagidonu (338 grt)
(Total Sail Area 240 sq m)

RECOMMENDATIONS ON FUTURE SHIP DESIGNS

The economic analysis of the measured fuel savings has shown benefits and rates of return which cannot be ignored. Together with the ability to theoretically predict the performance of other vessels, this will form the basis of guidelines for evaluating any small shipping operation contemplating auxiliary sail.

The EIRR has been calculated from historical fuel costs, sail-motor fuel savings verified by the Project, route fuel saving factors based on wind strength and duration statistics, and the actual cost of sail retrofitting. A payback period for the investment of less than two years is expected.

The analysis shows the value of planning sail retrofitting and ship routes to match the prevailing winds. In Fiji, if two ships are retrofitted to service the most favorable wind routes, the EIRR would be 123 per cent at a service speed of eight to nine knots. If six or seven more vessels are converted to service all other routes, except the least favorable up-wind courses, the EIRR would be 30 per cent.

These figures are for the existing vessels, retrofitted and maintaining normal service speeds. If lower speeds are acceptable, or if pure sail is used when conditions are suitable, the benefits are much greater. For instance, if pure sail is used for 10 per cent of the time, the EIRR more than doubles.

It is clear from the results of this Project that no commercial ship should be designed or built without considering auxiliary sail and analyzing route patterns. It is also clear that any ship in the general size range of relevance to the Project which was specifically designed for auxiliary sail would have much higher efficiency than *Na Mata-I-Sau,* with consequent increased fuel savings compared with the equivalent motor ship.

Layout

Na Mata-I-Sau was fortunate in having a layout enabling a reasonable sail plan. All ships are not the same and designers of new vessels must achieve a compromise between superstructure, cargo handling systems and an effective balanced sailing rig. In general, simple sail systems take up more space than more complex and costly ones and a trade-off must be made between space and cost.

Propulsive Efficiency

The Project has demonstrated, through instrumentation, the low propulsive efficiency of *Na Mata-I-Sau* (and probably the majority of ships like her round the world). It has also highlighted the poor part load efficiency of the propulsion system and the high drag caused by the propeller in the pure sail mode (about half the total ship resistance).

The whole field of propulsion needs to be considered very carefully, starting with ship resistance itself. In recent years, ship design has concentrated on carrying, or functional capacity, within limited vessel sizes. This has produced boxy shaped vessels with high block coefficients and consequent high resistance coefficients. For multi-purpose vessels, as for most of the Fiji fleet, in which ship size is dictated by factors other than pure carrying capacity, a different design philosophy can be used, which is sensitive to ship resistance.

The cost calculation must be done to allow the maximum waterline length so that desired cruising speed occurs at low speed length ratios. Block coefficients should be a minimum, consistent with the function of the ship. It should be noted that a ship can consume many times her capital value in fuel during her working life and that the resistance coefficient of grossly similar vessels of the same displacement can vary by as much as 20 per cent.

The effect of vessel trim was also demonstrated in the Project and adequate ballast tanks must be incorporated in the design.

Propeller efficiency, both in terms of ships' lines and propeller design and matching, is critical for all ships. On ships with auxiliary sail, when power from zero to maximum is required across a range of ship speeds, the problem is more complex and necessitates a variable pitch propeller for reasonable efficiencies. The propeller needs to feather for pure sail and provide pitches to suit a range of speed to power settings. The Southampton University analysis shows that the pure sail performance of *Na Mata-I-Sau* would improve by 30 per cent without the fixed propeller drag.

For vessels destined for use on routes with favorable winds, the predicted mean sail-motor condition should be the design optimum, rather than the usual motor ship calculation with sail-motor as a compromise. Most modern power plants are designed to operate efficiently within a narrow range of rated speeds. For sail-motor applications, efficient part load operation is essential and engine characteristics must be examined.

Twin engine installations offer a much wider range of part load options. In developing world operations where spares and service facilities are sparse, multiple engine installations will also contribute to vessel safety.

Sail Systems

The Project has indicated that the level of sail handling on *Na Mata-I-Sau* was acceptable whereas on *Cagidonu* (under her original rig), with conventional sail handling, it was not. Automatic sail handling is, therefore, essential and control and trimming simplicity is important. High technology

wind lift devices, with lift coefficients three or four times higher than conventional sails, are being developed and may be indicated if space or layout restricts soft sails.

It will be interesting to monitor *Cagidonu* with her new furling, less cumbersome rig. The stability and noise reduction of sail may commend themselves to the crew, or sail may be used solely to reduce fuel consumption. In any event, over the next year, *Cagidonu* should provide a solid data base for motor ship auxiliary sail performance in many conditions.

QUESTIONS AND ANSWERS

Q: Regarding your remark about the steel mast, it is common for ships to have steel masts and spars. Wouldn't there be marginal benefits from a modern design in steel? (Prof. J. King)

A: My objection was not that they were steel but that they weighed seven tons. For ordinary aluminum, extrusions are not expensive and these are easier to buy off-the-shelf.

Q: Did you consider other energy savings measures instead of putting the rig up, as I suspect that the vessel's propeller efficiency was probably very low? (Mr. C. Palmer)

A: Other savings could be made but we were conscious of the fact that if the vessel had poor propeller efficiency, the more that savings could be obtained from sail assist.

Q: What was the capacity of the cabin or deck? In Solomon Islands, the only way to travel is by boat and passengers stay on deck under an awning fitted to the main mast. (Mr. W. Mapuru)

A: There was an awning for 50 passengers on deck. It was significant that under the awning, passengers could not tell if the sails were being handled. Sails could be furled without disturbing passengers. During this project, we were aware that we could not take passenger space.

Q: Did the stability of the vessel with sail comply with statutory regulations after allowing for wind heeling moments? (Mr. G. Davison)

A: I was not aware of any on Fiji, but we complied with all known requirements.

Q: Did the vessel meet the 1966 Load Line Convention requirements? Like most nations, Fiji is very likely a signatory. (Prof. J. King)

A: I really am not aware of any requirements in Fiji at the moment.

Q: Did the vessel experience downwind and any rolling due to sail? (Mr. A. Marchaj)

A: Most winds in Fiji are 10-12 knots. We were more or less on the wind most of the time.

Q: Is it possible to use standard sails? (Mr. A. B. Thakur)

A: Sails are not very expensive, about US$7,000. We cannot standardize. We can produce guidelines on budgetting, but each sail is different.

Q: How about rigs? (Mr. A. B. Thakur)

A: There are standard sections of rigs.

Power Routing: Optimal Sail-Assisted Engine Use Strategy

James Mays*

INTRODUCTION

This paper defines and discusses the concept of power routing as distinct from the course-only weather routing traditionally practiced. We focus on the concept of power routing as applied to sail-motor vessels. A methodology is described for sail-motor operation that determines the optimal use of engines under different wind conditions.

ROUTING

Ship weather routing is a procedure whereby an optimum route is developed based on the forecasts of weather and seas and the ship's characteristics for a particular transit. Within specified limits of weather and sea conditions, the term optimum is used to mean maximum safety and crew comfort, minimum fuel consumption, minimum time underway, or any desired combination of these factors (Bowditch).

Ship weather routing is generally regarded as falling into three different classifications: climatic, strategic and tactical. These differ from one another according to the scale of time or distances involved. For the purpose of this discussion we will confine our attention to weather that directly affects the operation of a vessel. Thus, winds and waves are of primary interest. Precipitation, pressure and temperature, except in rare circumstances, do not substantially impede navigation.

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Oceanic currents and tidal streams are also of concern to the navigator in practice. Oceanic currents are difficult to map on a daily basis and are usually accounted for by long-term averages such as those depicted on pilot charts or marine atlases. We shall discuss the concept of power routing principally as it relates to the wind (which is responsible for most of the wave motion classified as 'sea'). Tidal phenomena are predictable but may be influenced by winds or atmospheric pressures that deviate from the seasonal normal. The adaptation of power routing to tidal streams is not covered.

Climatic Routing

Climatic routing refers to route preselection when actual weather conditions are not known. English, Portuguese and Spanish navigators during the age of exploration built up a wealth of information on prevailing sailing conditions in the Atlantic, Pacific and Indian Oceans that was invaluable to their successors. The acquisition and publication of this type of information were formalized under M.F. Maury for the U.S. Navy over a century ago. Maury collected, analyzed and archived log books to determine the most favorable routes, on average, for different ocean passages by season. His method is still used today in the pilot charts. Other publications that discuss this technique are various sailing directions published by different nations and *Ocean Passages for the World* (Hydrographer of the Navy).

What distinguishes climatic routing from the other types is the absence of any real-time information such as present or forecast weather. Recently, the great body of climatological information that has comprised the pilot charts and marine atlases of earlier years has been computerized, so that thousands of voyages over any choice of route during any month of the year can be simulated. Statistics of winds, waves, currents and ship passage times can be conveniently compiled and compared. When coupled with speed and ship motion prediction programs, this technique is very useful in preliminary ship design and in vessel schedule planning (Mays, Fazal and York, 1984).

Strategic Routing

Strategic routing is performed when weather is forecasted for three or more days. The choice of course(s) from the departure point to the destination depends upon the expected weather. This is the method of routing used principally by commercial vessels transiting the mid-latitudes of the North Atlantic and North Pacific where low pressure systems can cause rapid and sometimes violent weather changes.

Routing services are provided by the commercial sector as well as by weather agencies of several maritime nations. The dominant private organization is Oceanroutes, Inc. that provides over 1,000 routings per month. The British, Dutch, German and Japanese also offer routing services for a fee.

A ship under routing is advised of the recommended optimal route just before departure. The routing service agency considers vessel type, size, speed and payload when coupled with forecast wind and waves that will affect speed, motions or inflict possible damage to the hull and cargo. Once underway ships transmit daily reports on their progress and current weather conditions. The service agency sends to the ship updates on route forecasts or diversions as needed. Once the voyage is completed, it sends an end-of-voyage report compiling weather and positions enroute to the ship's master and the client (owner, operator or charterer). Economic advantages related to shorter passage times are generally estimated at five per cent. Damage reduction due to heavy weather avoidance has been estimated to be 15 per cent.

Strategic routing has benefited greatly from space technology as exemplified by polar orbiting and geostationary observation satellites. Images of land and sea are transmitted to earth and analyzed for weather features. Instruments aboard the current generation of spacecraft will allow much more accurate observation of surface winds, waves and currents, thus significantly increasing the value of routing operations.

Supercomputers are used by national meteorological agencies for the prediction of global and regional weather as well as ocean waves. For example, the European Center for Medium Range Forecasting in Reading, England, a consortium of many European countries, provides current weather analyses and prognoses for up to ten days. It is this type of modeling, combined with satellite sensing, which incidentally is provided for the entire world, that will benefit greatly all routing operations. Telecommunications using computers and satellites has already begun to make an impact on processing and delivery of weather and ship routing products to the shipping fleet.

Tactical Routing

Tactical routing is practiced when the weather being experienced is different from forecast and when course and speed deviations are required. Tactical routing refers to the maneuvers undertaken now or in the near future to deal with existing weather conditions. It is differentiated from strategic routing only in the time scale involved. Usually it refers to a speed or heading change to lessen the chance of damage owing to adverse seas.

ROUTING POTENTIAL FOR SHIPS

Commercial vessels generally travel at a speed between five and 25 knots depending upon size and type. Small cargo and fishing vessels typically are designed to sail under 15 knots; ocean-going container ships carrying high value or perishable cargo may speed along in excess of 25 knots. Weather systems (for example, depressions, fronts, anticyclones, etc.) travel between 10 and 20 knots, which is the speed range of most ships. In this paper we focus on the application of routing to sail-motor ships as opposed to sail-only or power-only vessels.

It is convenient to set the date of beginning of the engine-powered vessel at the turn of the century. Sail-powered vessels evolved over the millenia but by the turn of the century, power plant engineering and screw propulsion had advanced to the point that sail could not compete except in some specialized trades. Since that time sail technology has been dormant compared to the advances in steam and motor ships.

The sail-assisted vessel uses both wind power and motor power for its propulsion. Much of the experimentation in such a mode during the waning years of sail was not successful because the dynamics of such a dual system were not well understood. At that time, many vessels designed to have the advantages of both sail and power ended up with neither. They were not weatherly under sail, they were slow under power, and were a bad compromise when both modes were employed.

Much has been written about the advantages of combining sail and power John Fyson of the Food and Agriculture Organization (FAO) talks about the synergy of: 2 + 2 = 5. It is possible, however, to get 2 + 2 = 3, unless the vessels are designed and operated to achieve the synergy. We will confine ourselves principally to the discussion of how best to operate these hybrid vessels (see also Letcher, 1982).

With respect to routing, sail-only ships sought out favorable strong winds that speeded them to their destination. During the age of sail, masters had few tools to predict weather beyond a day or so. However, they were able to exploit the better known climatic systems such as trade winds and to avoid the doldrums. Sail vessels were entirely at the mercy of the weather. Absence of wind meant no progress to the destination. It also increased chances of scurvy and malnutrition owing to extended landfalls and brought about excessive wear and chafe on sails, slackening rigging, and straining and racking of the hull owing to rolling motions inflicted by waves.

But, winds greater than 40 knots were also unfavorable because these built up high seas causing damage to the rig, casualties among the passengers and crew, and slower passage times. Sails had to be reefed to prevent broaching or being knocked down. Winds between 15 and 25 knots on the beam or on the quarter were most desired. Winds coming from the direction of travel required tacking or wearing ship. The navigators and sailing masters of these vessels were alert to the slightest wind shift. Using our routing terminology, we would say that they planned their passages using climatic routing, but sailed them using tactical routing. Strategic routing was denied them: they did not have the advantage of a three, five, or ten-day ocean weather forecast.

As a result of being dependent exclusively upon the weather and having little or no means to predict it, sail-only ships had passage times that were often very erratic. Thus, although the early motor ships could not sail as quickly as the sail vessels, they were attractive to traders looking for reliability because they arrived in a more predictable fashion, barring any malfunction.

In contrast, modern motor and steam ships look upon weather to be avoided. Beaufort force four or above is regarded as adverse in most charter party agreements. The Sailing Master needed at least force four for his sails to draw properly! The conventional power vessel suffers involuntary speed losses owing to wind resistance and wave forces, but after a certain point is compelled to lower engine revolutions, or make heading changes to reduce stresses and improve crew and passenger comfort. Thus routing as we have come to know it, often succeeds in providing economical routes by avoiding expected heavy weather, whereas a sailing vessel might well steer for stronger winds if they could be exploited.

The design of new sail-assisted vessels, or the conversion of existing motor ships, is discussed by others at the Conference. The balance between sail and power depends on a variety of factors: for example, cargo handling, classification society regulations, payload, minimum speeds and climatic conditions. The properly designed sail-assisted ship should be able to exploit winds of up to say, 40 knots, before reefing. It will be more seaworthy under a press of sail than her nonsail sister ship and would not incur the risk of being becalmed. Furthermore, there are two independent propulsion systems that should lessen the risk of drifting towards a lee shore.

The sail-motor vessel will be able to exploit the advantages of higher apparent wind speed and direction by using high lift/drag devices (efficient sails, foils, rotors, etc.). Use of the engine also provides a base speed that reduces the component of induced hull resistance experienced by sail-only vessels in windward operation.

To recapitulate, it may be helpful to compare vessel types (sail, motor, sail-motor) versus routing scheme (climatic, strategic and tactical). Table 1 presents these comparisons.

Table 1

Propulsion System	Routing Technique			
	Climatic	Strategic	Tactical	Power
	1600 — present	1950 — present	always	
Sail 1900	—hull, rig design —economic estimates —pilot charts, sailing directions and atlases	—transocean sailboat races —course selection only	—tacking, reefing heaving to	
Power 1900 — present	—hull design and power plant sizing —economic projections	—Oceanroutes, UK Met Office (Bracknell), Dutch Met Office (KNMI) —traditionally course selection practiced	—voluntary speed reduction and heading change in heavy weather	—possible, but not yet practiced
Sail-Power 1980 ...	—hull, rig and power design and sizing	—largest benefits by exploiting course and power selection	—best tacking angle —optimal power/sail setting	—most economical throttle and sail setting for optimal passage

POWER ROUTING

With this background on the various routing techniques and how they are applied to different ship propulsion systems, we are prepared to discuss the main subject of this paper: power routing. Strictly speaking, strategic routing implies the ability to select the best sequence of courses and power settings along an intended route to achieve an 'optimal' passage. In practice, vessel operators typically decide on one power setting for the entire passage but will follow the courses given in a route recommendation. For liner vessels, power is varied only to guarantee the scheduled arrival time. The routing authorities also make little effort to advise vessels as to the most effective engine use strategy that complements the recommended route. The mathematically optimal solution has to be performed by a computer that has perfect or at least near-perfect forecast information over the entire duration of the passage. Obviously this is impossible, so that most strategic route recommendations (course only) are based on three- to five-day forecasts and good guess work as to what will happen beyond that time.

Whereas strategic routing is generally used for ocean-going vessels on long transoceanic passages spanning many thousands of nautical miles, the vessels that are the subject of the Conference generally operate on voyages of up to several hundred miles, usually shorter. Short distances compared to the scale of the weather changes do not permit any real choice of headings except to leave islands and reefs enroute to a destination on one side or the other. Over such short time period (several hours to a day or two), the present weather is a very reliable guide to tomorrow's weather either through 'persistence' or local knowledge regarding impending changes. Also, the regional area under discussion is in low latitudes, which are usually characterized by predictable weather: onshore/offshore winds, monsoons, trades, doldrums. Catastrophic weather caused by tropical cyclones may not be entirely avoidable; but at least there are forecast and warning centers in Australia, Guam, India and Philippines that provide a variety of weather prediction products.

Power routing is routing when the only control that can be realistically varied is power setting. We shall extend the notion of power for the sail-assisted vessel to include the balancing of power between the rig and the power plant. Assume we have no choice over course and that we have confidence in our forecast. What is the most economic balance of engine and sail to use during the passage? The more we use the engine, the greater the fuel consumption and hence, cash expense. Alternately, the slower the passage, the fewer number of passages per year and hence lower annual payloads we can carry ('opportunity cost'). A simplified mathematical model of power routing is presented in the Annex.

Table 2
Voyage Costs = Fuel Costs + Opportunity Costs

		Fuel Costs	Opportunity Costs
Engine	increase	increase	decrease
Speed	decrease	decrease	increase

Sails augment power, increase speed at the same power setting and reduce fuel consumption. Suppose our sense of the right speed to choose for a vessel is that which just matches what we are willing to pay for the vessel's operating expenses that are speed-related (fuel and lubricants) as balanced by how important it is for us to arrive at our destination at any specified time. We have balanced our utility of arriving as quickly as possible with the cost of fuel consumption.

The 'cost' of later arrival might not be a real or recognized expense. It may be the case that the vessel operators like to go as fast as they can, thereby imputing a high cost to slowness relative to fuel expense. If this is true, then the method of power routing is still valid, but the benefit will be less.

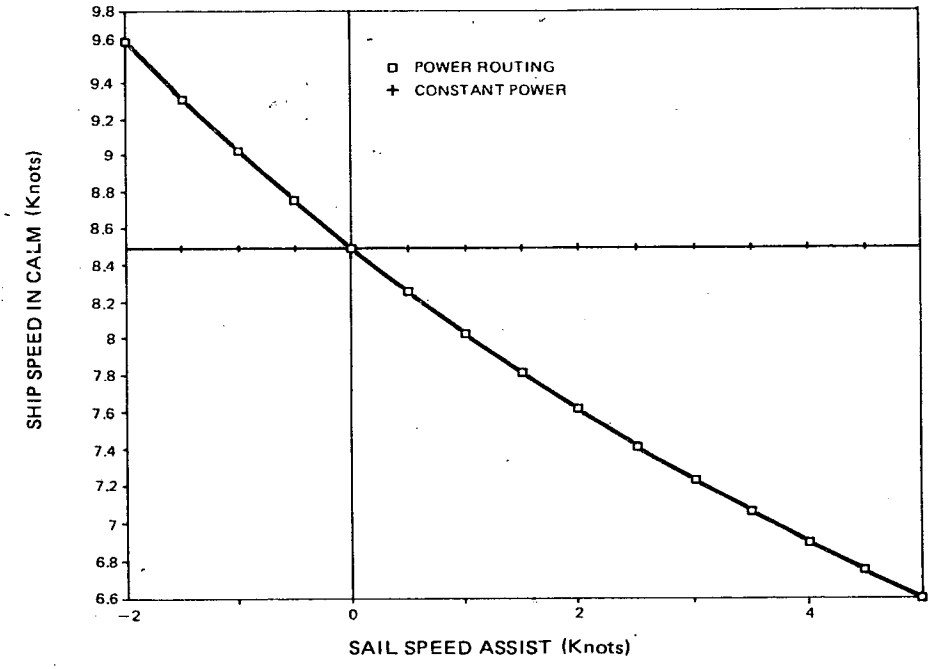
One may argue that the operators who run such vessels do not read economics textbooks and that human behavior refuses to be categorized so easily. But it is also true that throttle settings are set based on arrival times, total power available, levels of vibration and, sometimes, on perceptions of fuel economy. So regardless of the motivations (fuel economy, noise, lust for speed), an equilibrium speed is found. We merely seek an equilibrium speed, factoring in the economics of sail-assistance.

The benefits of power routing depend on the vessel operator varying the engine revolutions per minute (rpm), or the throttle setting, as a function of sailing conditions. We have included three figures to illustrate the use and economic benefits of power routing for a vessel comparable to the Fijian vessel, *Na Mata-I-Sau*. As discussed above, we are always trading off the benefits of fuel savings against the costs of later arrivals. Assume our vessel's normal service speed is 8.5 knots. In other words it has been determined that for this vessel, in this trade, 8.5 knots is the appropriate equilibrium speed. Now assume that by addition of sails we can get speed increase in favorable winds (and some penalties in head winds). In Figure I 'sail speed assist' along the bottom of the graph refers to this speed augmentation (diminution) resulting from the use of the sail rig.

We experience speed loss in head winds even though we may choose not to set the sails because the presence of the mast and rigging increases

Figure 1

Ship Speed in Calm
(no wind speed = 8.5 kts)



resistance in this direction of travel. We seek the level of engine use appropriate to different levels of sail-assistance. The degree of engine use can be stipulated by one of several means: rpm, fuel consumption or ship's speed. The type of power plant has a direct bearing upon the relationship between these three measures. For the purpose of this discussion we will use a surrogate measure S_c, the speed of the ship in a calm, rather than rpm. This is the speed at a given power setting that the ship would make in a calm sea with no wind. Alternatively we could have stipulated rpm.

Our goal is to determine what S_c the vessel should be operated at to provide maximal economic return for the existing sailing conditions. The curve plotted in Figure 1 shows the speed in calm S_c that should be selected depending upon the sail speed-assist provided by the sails. The horizontal line at 8.5 knots assumes the null case where we keep the engine output constant at a power setting equivalent to S_c of 8.5 knots.

Figure 2 shows the same results, except that instead of showing the results in terms of the speed in a calm, we add that 'sail speed-assist' to S_c to give the actual speed the ship would experience. The curve marked by '+' is again the null case corresponding to 'sail assistance' at a constant engine setting. The other line (delineated by □) is the resulting ship speed under sail and power using power routing. Note that as 'sail speed-assist' increases, we reduce throttle to compensate. Our throttle reduction (lowering S_c) is not to keep speed constant, but to balance the cost of fuel against the inferred costs of arriving later. In Figure 1, we can show this by noting that when 'sail speed-assist' is 5.0 knots, the power level we select would give 6.6 knots in a calm. The speed through the water is 6.6 + 5.0 = 11.6 knots as seen in Figure 2. When going to windward in conditions that the ship might experience a speed loss of two knots, our tactic is to increase power to give the equivalent of 9.6 knots in calm (Figure 1) or 9.6 - 2.0 = 7.6 knots as seen in Figure 2. We assert that power routing, if conducted properly, should always provide benefits over the comparison case of sail-assistance at constant power setting.

Figure 3 shows the savings for our hypothetical interisland trader under power routing, as compared to using a constant engine strategy (speed in calm of 8.5 knots). In the degenerate case when sail speed assist is zero (no wind), then there are no benefits. However, as sail speed-assist increases, the economic benefits increase over the straw-man example using constant engine speed (S_c = 8.5 knots). Note that benefits also increase under head winds.

In practice, the power routing technique is easily implemented. Simple charts or tables showing desired rpm as a function of wind conditions can be posted in the wheelhouse. Alternatively, as we demonstrated above, the vessel speed in a calm, S_c, versus 'sail speed-assist' could be used.

Figure 2

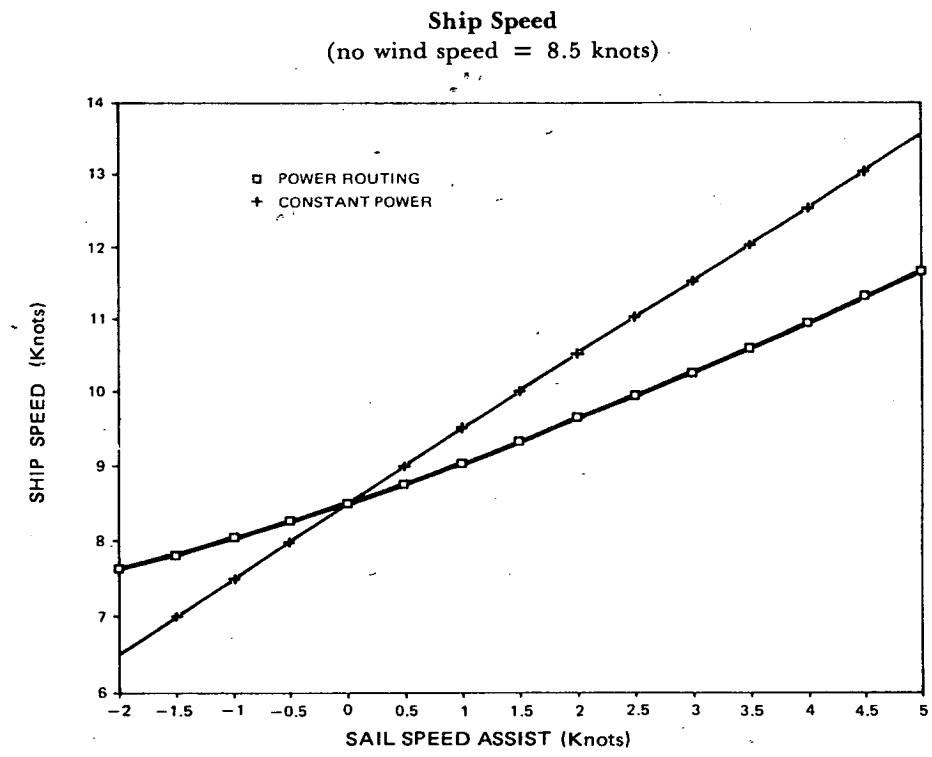
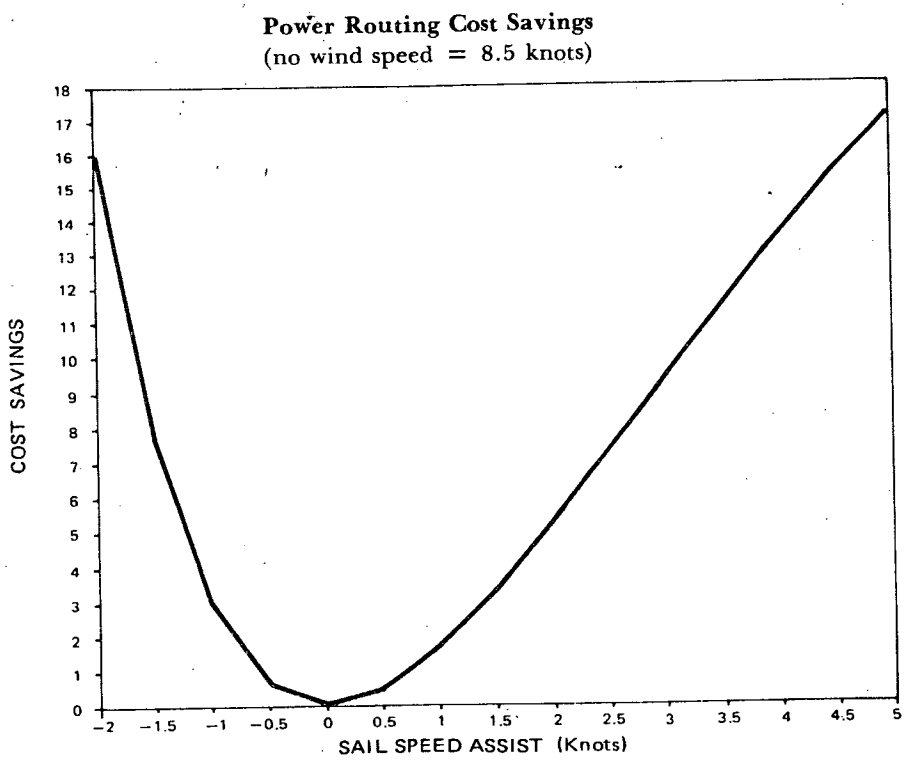


Figure 3



ANNEX

SIMPLIFIED POWER ROUTING MATHEMATICS

Assume costs to be minimized are borne between fuel costs (cash) and an opportunity cost that increases with the duration of the passage. It is often difficult to attribute a value to the benefit of going faster; nevertheless, determining the relative benefit of a speedier passage versus added fuel consumption is practiced everyday.

We used S_c (calm water) speed as a surrogate for rpm. The optimal S_c is sought given the anticipated wind-assisted speed increment S_w and the economic equilibrium speed S_e and the power (exponent) of the fuel consumption curve γ.

Definitions:

F	=	fuel consumption (liters/hour)
S_e	=	economic or equilibrium speed in calm (knots = nautical miles (nm)/hour)
S_c	=	speed that vessel could make with no wind at various rpms (knots)
S_w	=	speed increment (decrement) due to sail assist (knots)
S	=	ship speed through water $S = S_c + S_w$ (knots)
T	=	time of passage (hours)
α	=	cost of fuel ($/liter)
β	=	cost of time ($/hour)
δ	=	constant relating speed to consumption
γ	=	exponent of fuel consumption
k	=	passage cost rate $= \alpha F + B$ ($/hour)

Annex (ii)

Assumption:

$$F = \delta S_c^{\gamma} = \delta (S - S_w)^{\gamma}$$

then by calculus of variations minimizing the total cost per nautical mile (k/s) results in the equation:

$$S_c^{\gamma - 1} [S_c + (\gamma / (\gamma - 1)) S_w] = \beta / \alpha \delta (\gamma - 1))$$

Solving this for S_c gives the no-wind speed the throttle should be set at for optimal performance. In most cases, we do not know α, β or δ but if we assume that the wind is zero and then solve the equation we get:

$$S_c = S_e = [\beta / (\alpha \delta (\gamma - 1))]^{1/\gamma}$$

resulting in the information about α, β and δ needed to solve for the optimal S_c. In the computation performed for the example in this paper, we assumed $S_e = 8.5$ knots and $\gamma = 3$.

Clearly the physics of wind-assisted propulsion is much more complex than described above. Nevertheless, the qualitative behavior is similar and can be modelled numerically given sail-assisted performance curves of the vessel.

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QUESTIONS AND ANSWERS

Q: Does the sail-motor concept suggest the use of rigs different from those for vessels that operate under sail alone? (Mr. C. A. Marchaj)

A: Sail thrust is related to apparent wind speed and direction. The use of sail together with motor propulsion produces higher apparent wind speeds resulting in greatly increased thrust and higher sailing angles, allowing the use of more efficient rigs. The usual disadvantages of sailing hard on the wind are caused by the large side forces of the rig that must be equalized by the hull. Under pure sailing, the hull side force can only be created by large amounts of leeway resulting in increased (induced) drag, further slowing the vessel down. Under sail-motor propulsion, vessel speed is kept at or near some nominal speed which permits hull side force to be maintained at much lower leeway angles and hence lower induced drag. Thus rigs that are optimized for on the wind sailing will be used to greatest advantage in motor-sailing.

Q: How are the relative weights between added fuel costs and extra speed determined? (Dr. C. J. Satchwell)

A: I refer you to the Annex of my paper which describes the mathematical basis of power routing. The last equation shown displays the relationship between operational costs (fuel) and opportunity costs, as a function of no-wind economic speed.

Q: What percentage cost savings are possible under power routing as opposed to some other engine use strategy? (Mr. G. Hughes)

A: The answer depends on what power routing is being compared to. If the alternative is constant speed, then the cost savings are expected to be in the order of five per cent.

Q: Weather routing services are regularly used by conventional merchant ships for reasons of safety and economy. What benefits would accrue to sail-assisted ships? (Mr. C. A. Marchaj)

A: Papers on that subject were given in the Windtech 85, (Southampton) and Comsail '80 (London) Symposium. The greater the effect of weather on a ship, the greater the improvement in safe handling and economical choice of route. The *Usuki Pioneer* regularly uses a weather routing service.

Sail in Interisland Shipping*

Harold C. Brookfield**

INTRODUCTION

This is in no sense a technical paper but one concerned with concepts and issues and one which focuses on the demand side: What is required of interisland shipping and what is the potential role of the sail-motor concept? These are questions that can be tackled in several ways. Perhaps the most straightforward one is by looking at island development problems and the role of shipping in them, then assessing the reasons for deterioration in the quality and quantity of shipping service in some areas and considering how significant ship operating costs have been. This I have done before (Brookfield, 1979) and will not repeat here.

What I have decided to do is ask one question through another. I approach the question of the potential place of sail-motor service in interisland shipping by asking why traditional, old-fashioned sail went out of service, and particularly why the decline of pure sail continued and even accelerated in two island regions namely, the Caribbean and Indonesia, during the 1970s when fuel costs were rising. The answer to this question may provide a better way of looking at the potential of modern sail in the context of interisland shipping. I am not considering the potential of modern sail in transocean bulk trades, or in any other area, in this paper.

Most of the discussion that follows is based on trends and conditions in the Pacific region, but reference is also made to the very different conditions in Indonesia and the Caribbean where pure sail and motor-assisted

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sail survived longer and more effectively (in Indonesia they remain important). The purpose is to analyze the cost and other operating considerations that have led to motorization, as far as such analysis is possible given the limited quantitative information available. I suggest that the need for higher ship utilization has been a major factor in change. If this hypothesis is correct, it suggests in turn that the fuel economies and other advantages to be derived from the introduction of modern sail-assist designs will not by themselves guarantee widespread adoption, except in certain limited areas of service.

The paper therefore begins with a historical review of change in the Pacific region, necessarily covering the whole colonial period since the second half of the 19th century. A comparative analysis of trends in Indonesia and the Caribbean follows. The second part of the paper begins with a review of the economic considerations governing the operation of interisland shipping in the context of the transport task. The potential role of modern sail-assisted designs is then assessed in the wider context of necessary innovation in interisland shipping.

HISTORICAL TRENDS IN PACIFIC SHIPPING

The main initial burst of colonial development in the Pacific islands region took place only in the second half of the 19th century when steam-powered vessels were already winning the competition with sail on the world's long-haul routes. Although most of the new interisland ships were at first wholly wind-driven, these were already interfacing with steamers at regional main ports. In the islands, the superior handling qualities and greater cargo-carrying capacity of the steam-powered vessels quickly gave them an advantage over the large fleet of locally built sailing canoes, some of considerable size. Thus, although canoes were used in island trades well into the 20th century, they were steadily displaced.

By the 1920s, locally owned sailing and motor-assisted sailing vessels were still serving the more isolated islands and those parts of main island coasts where trade was lean, whereas steam-powered vessels belonging mainly to large companies held all the more prosperous trading areas (Couper, 1967). Up to this time many island communities were operating their own schooners and cutters; some of these bought second hand from European traders, some locally built to European design. Hardly any of these operated profitably, and most of the individual and cooperative owners were deeply in debt. Very few survived to 1940 and still fewer into the postwar period. By the 1970s, the only significant areas remaining to locally owned vessels, some still with sail but a high proportion without, were the very local feeder

services of such areas as the Ha'apai group of Tonga, the trade between the Yasawa islands and Lautoka in Fiji, and outlying areas in eastern Papua New Guinea. Almost all other shipping capacity was based in the islands' main ports, and almost all of it operated only under motor power. In the 1980s even less of outer-island-based shipping survives.

To understand these trends it is necessary to understand trends in vessel ownership and in the trading system as a whole. In the Pacific, large companies entered the island shipping business at an early date and quickly became vertically integrated corporations that owned or controlled plantations, trade stores, interisland and long-haul shipping, and both the major trading houses and their subsidiaries. A number of island companies formed in the early years were progressively taken over by the major companies based in Australia, New Zealand and France. These companies provided both long-haul and interisland ships in two main patterns: in one, vessels operated both between metropolitan ports and a large number of island ports and anchorages on circular or loop itineraries; in the other, long-haul ships interfaced with interisland ships at island main ports, and in some countries the main internal services were also operated by the large companies. This pattern lasted up to about 1970, and it left only some feeder services to small companies and owner-operated ships, a 'fleet', if that is the right term, consisting mainly of third-hand to nth-hand vessels, some of them retrofitted former sailing ships, and many of them very unsuited to the tasks they were called on to perform. The casualty rate among them was very high, and has remained so in areas where this pattern survives.

In the late 1960s the 'effective fleets' in Fiji, Tonga and Kiribati/Tuvalu consisted of 33, 14 and 7 ships, respectively, totaling 1,559, 1,844 and 720 net registered tons. A number of smaller wooden-hulled ships are not included in this total. Of this tonnage, 57 per cent belonged to governments and government departments (including the largest ship, Tongan, which also voyaged overseas) and 22 per cent to vertically integrated producing and trading companies. In Vanuatu and Papua New Guinea, the proportion belonging to the companies was much higher, so that in the five island territories (as they then were) more than 50 per cent of the fleets were company-owned, and another, 25 per cent belonged to governments (Couper, 1967; Dunbar, 1981; Brookfield with Hart, 1971). Furthermore, this dominant share comprised all the larger vessels. Governments already operated services in areas that were not of interest to the companies or private owners. Between 1968 and 1978 the larger companies stopped internal shipping in all areas except Papua New Guinea, there was a rather rapid turnover of ownership of vessels handling the 'main' services of the islands. Surviving companies are small and undercapitalized with the exception only of those serving the most profitable inter-main-port or inter-main-island

routes in Papua New Guinea and Fiji. A number of services were withdrawn, so that governments were forced to enlarge their operations. The effect on island communities is well exhibited by what happened in Fiji, where between 1969 and 1974 the number of island calls declined from 1,032 to 787, although the number of voyages declined from 493 to 466 only; on inward voyages to Suva, the average copra load increased from 11.6 to 16.6 tons per journey. Regularity also declined in most places (UNESCO/UNFPA Project, 1977, pp. 262-264). The greatest loss of service and regularity was suffered by small, outlying places.

All this happened before the oil-price shocks of the 1970s began to bite, and the situation has stabilized since that time, largely through greater government intervention in one form or another. Almost all government services operate at a loss, a fact that has led to increasing pressure for renewed privatization since 1980. There is very little modern tonnage in the commercial fleets, except in Papua New Guinea, and throughout the Pacific there are many fourth-hand or fifth-hand ships; in Fiji one 'newly introduced' ship in the early 1980s was a partly refitted vessel built in 1905. The maintenance costs of one company running a small group of aging second-hand ships reached 30 per cent of total operating costs in 1983.

We shall examine the reasons for the decline in service in the Pacific in the next section since they are highly relevant to the prospects for the innovation of modern sail. However, since old-fashioned sail had all but vanished before the first of the oil-price shocks the Pacific case can tell us nothing about the reason for discarding sail during a period of rising fuel prices. A briefer excursion into two other areas will better set the scene for analysis.

THE CARIBBEAN AND INDONESIA

The pattern of vertically integrated trading and producing corporations, of whose operations interisland shipping formed a part, was characteristic only of the Pacific islands, where it penetrated much more deeply than in other maritime colonial regions. It may perhaps be directly correlated with the early demise of sail in the Pacific. In the eastern Caribbean (Brookfield, 1978), on the other hand, schooners continued to operate a large proportion of the interisland trade well into the 1970s, and these small-company or owner-operated vessels often continued to use pure sail, except for getting in and out of harbor, as late as 1972; in the northeastern Caribbean and around Haiti this mode still survived in 1980. In the Caribbean, big metropolitan companies never developed the sort of vertically integrated operation in which interisland shipping had a necessary role.

The schooners represented a very old form of interisland trade in the Caribbean, going back to the days of slavery when they were manned by freed or trusted slaves and handled most of the interisland traffic, long-haul ships being employed only on the runs from North America with food, from Africa with slaves, and to Europe with sugar, cotton and other exports. The schooners carried almost all trade and passengers between the islands, from Guyana and Trinidad to Jamaica and Belize. They continued to do this well into the 19th century, although after the 1880s tramp steamers became serious competitors. In 1890 the Canadian government began to subsidize shipping services between Canada and the West Indies, and in 1919 liner services were initiated, with the ships calling at all main islands and thus incidentally providing reliable passenger and cargo interisland services. These 'lady boats' continued to run, wartime interruptions aside, until 1952, when their withdrawal due to unprofitability suddenly left the whole region with no internal service other than the schooners (Mohammed, 1969).

From 1955 this gap was filled by the West Indian Shipping Service, initially with chartered ships, then with two Canadian-supplied and Canadian-subsidized cargo-passenger ships that continued to operate until the 1970s. Some international cargo-passenger ships provided incidental service, but the schooners remained a major force in the eastern Caribbean, where their low freight rates provided an effective ceiling to what the motor ships could charge (Keirstead and Levitt, 1963). The main traffic handled by the schooners consisted of fresh foodstuffs inward to the urbanized food-deficient islands and transhipped general cargo outward to the minor islands. Bulkier commodities like rice and timber were carried longer distances, from Guyana to as far as the Windward Islands. Schooners were owned by individuals and very small companies, and general cargo was handled by agents; the fresh foodstuffs, however, were put on board shortly before sailing by hucksters or traffickers who had bought them on the farm or in the market and who sometimes traveled with their goods, and sometimes consigned them to market middlemen in the more urbanized islands (Brookfield, 1978). High profits were sometimes made, but by the middlemen rather than the carriers (Keirstead and Levitt, 1963). For the masters and crews, as one agent in St. Vincent put it:

> 'Vessels are never fully laden going south; the profit is north-ward carrying general cargo and usually fully loaded. The crews are not really large, though they are also stevedores, unlike on the 'iron boats'. But though wages are low, they make up for it on the pilfering and smuggling.' (Brookfield, 1978, p. 265)

Until the early 1970s the 'iron boats' and the schooners shared the trade with competition only at the margin. A review of the freight rates of the

West Indian Shipping Service showed the importance of a balance being preserved:

> 'In lowering rates we must keep in mind the consideration of the effect on the West Indian schooner if steamship rates become too low. That the schooners may gradually have to yield to the steamship and motor vessel is probably true, but any sudden elimination of the schooner fleet would be a terrible disaster to the Eastern Caribbean.' (Keirstead and Levitt, 1963, p. 29)

In any event, the demise of the schooner was sudden, and it took place in the 1970s. Between 1973 and about 1978 the schooner trade between the Windward Islands, Barbados and Trinidad was totally displaced by the iron boats, being some of the flood of second-hand ships displaced from the coasting trades of Europe and North America by new designs.

Indonesia

The situation in Indonesia has been more complex. *Prahu* shipping was displaced from the main routes by steam and European schooners before 1900 and the volume of trade handled in *prahu* declined rapidly between 1900 and 1925 (Dick, 1975). Dutch policy was to support the interisland services of KPM, which by 1920 had acquired almost a monopoly of the major services. During the depression, however, the low rates offered by the *prahu* brought a great deal of cargo back to them from the KPM and other traders. After the war the decline resumed; however, following the expulsion of KPM in 1958 and the formation of Indonesian companies, most of which had much poorer equipment (Ali, 1966), the *prahu* were again able to command a significant share of trade along certain routes, particularly the timber trade from the outer islands to Java, which they continued to dominate into the 1970s (Dick, 1975). With up to 10,000 sail or motor-sail vessels operating in Indonesian waters in the 1970s, this was the largest remaining focus of commercial sail in the world. With each owner holding no more than a few vessels and each captain in touch with his own shore agents, the business is highly atomized. Yet, in the Dutch period and until 1960, these vessels competed with better-capitalized enterprises as part of a distribution and collection system that was highly integrated, through tied middlemen, to a group of import-export companies that completely dominated marketing (Panglaykim, 1968). Subsequently, following the failure of state marketing from 1960 to 1965, they had to compete with increasingly internal shipping companies that were becoming stronger.

Unlike the Caribbean schooner, the *prahu* survived, but it did so through change. The *prahu* had survived the overwhelming monopoly power of KPM in pre-1941 Indonesia by being able to offer rates which, even with cross-subsidization, KPM could not match. In more recent years, however, they have had stiff competition from an emergent *lokal* sector of interisland shipping composed of small, wooden and steel-hulled motor ships of up to 175 grt and, like the *prahu*, held by a large number of owners most of whom are of Chinese origin. Neither sector enjoys the advantages of the formal (or *nusantara*) sector of Indonesian shipping, which in the post-1965 period was able to re-equip itself with loans at a negative interest rate in terms of the then prevailing rate of inflation (Dick, 1975; 1978). But the *prahu* owners have adapted in other ways — first, by increasing the size of new building to give them economies of scale and, second, by making changes in organization.

Greater reliance on agents ashore, which has been an important element, was partly enforced. From 1964, all cargo handling in Indonesia was required to be carried out by licensed shipping firms, which have since become the main focus of *prahu* shipping in all ports; specialization by route and cargo has followed, 'permitting forwarding agents to provide almost regular liner service between main ports' (Dick, 1978, p. 245). They thus competed with the motor ships in all respects except speed and regularity, and these, too, have changed through retrofitting and new building with auxiliary motors. Up to the mid-1970s, only a minority of *prahu* were so fitted, but in 1976 a program was launched offering financial assistance for motorization in the interests of efficiency and more regular operation. Progress was at first slow, but since 1982 the rate of retrofitting has accelerated between 1,000 and 2,000 ships a year, so that by 1985 a substantial core fleet of motorized *prahu* could offer more frequent and regular service and enter and leave port without assistance (Direktorat Jenderal Perhubungan Laut, 1985). Rates remain unregulated, but considerable organizational loyalty is created by the practice of paying the crew a share of the profits rather than a wage (Dick, 1978), though a wage structure is now beginning to take the place of these arrangements on the motorized *prahu*. The *prahu* now have a slightly larger share of dry cargo than the *lokal* vessels, in contrast with the position a decade ago. Although it suffers from a lack of port facilities that sometimes causes long delays, the Indonesian *prahu* fleet has remained an effective competitor for an important part of the internal trade, albeit at the margin.

SOME EXPLANATIONS FOR THE SURVIVAL AND DEMISE OF OLD-FASHIONED SAIL

In the Pacific, the Caribbean and Indonesia, sail was fairly quickly relegated to a feeder and local traffic role during the first quarter of this century. However, sail and auxiliary-motor sail persisted in the Caribbean and later enjoyed a strong revival in Indonesia, although in the Pacific motorized vessels completely replaced sail. It is not enough to say that distances sailed are shorter in Indonesia and the Caribbean, because in the areas in which sail survived longest in the Pacific they are not. Nor is it enough to say that labor abundance kept crewing costs low, because in Indonesia the deckhands' share gives them a much better income than laborers and small farmers on land (Dick, 1975). The problems of limited ship life, high maintenance costs, and low utilization efficiency were common in all three areas.

One conclusion is fairly clear. Neither the survival of old-fashioned sail in archipelagic areas nor its partial or total demise had much to do with the price of fuel oil. The reduction of the domain of sail to feeder and cross routes was most rapid in the era of coal-fired steamers when coal, bulked at island coaling stations, was entirely manhandled. Scale, speed and regularity seem to have been the main technical advantages, coupled with the organizational advantages of shore-based cargo-handling and freight-forwarding systems and the ready availability of finance to the shipping companies. Business organization was clearly a major factor in this early stage, and it has remained so. Sail survived in the context of 'informal sector' trading in those low-cost and small-unit areas where the interpersonal connections of informal trading continued to offer some comparative advantages. Nor should it be forgotten that subsidies in one form or another and preferential contractual arrangements gave the formal-sector companies an advantage in all three areas reviewed.

The recent history of old-fashioned sail is particularly relevant. In the Caribbean, the schooners were replaced in the 1970s, in spite of their lower freight rates. The small-company operators of the iron boats were able to get their ships off the scrap heap at low prices, and were then able to offer faster and more regular service. In the few years before this happened, the building of new wooden schooners had already tailed off; so thus, with inadequate replacements, the maintenance costs of the old wooden boats soared. Unfortunately, no detailed analysis is available to show how the balance of costs and returns shifted. What happened in Indonesia is clearer from the work of Dick (1975, 1978). Although preference in the allocation of finance for re-equipment went to the companies operating the larger ships in the *nusantara* fleet, both the powered *lokal* ships and the sail-operated

prahu were forced to reorganize their shore linkages and to use agents. In all important respects they were treated equally until the mid-1970s when the Government intervened with support for retrofit motorization of the *prahu*, making them far more comparable with *lokal* ships in the service they could offer. At the same time the wholly *pribumi* (Indonesian-by-origin) business system within which the *prahu* operated, benefits from numerous minor advantages over the mainly-Chinese business system within which the *lokal* fleet operated. In these circumstances the lower fuel costs of the *prahu* (many of which still operate only as motor-assisted ships) may have become a sufficient advantage to permit them to survive and even improve their share of traffic. But motorization was an essential element in survival.

The modern period in the Pacific found very little sail left to displace, but the changes in this area have been as great as in any other. There was the same introduction of second-hand former coasters from other trades as in the Caribbean, bought at similarly low prices. Some ships of as much as 400 grt were bought for as little as $150,000, and even now their market value is higher than the purchase price. Many of these steel-hulled ships are still not old by island standards. In Vanuatu the seven principal steel-hulled ships in the 1978/79 commercial fleet were built between 1951 and 1957 in Europe, Australia or Japan. The smaller wooden-hulled vessels span a much larger age range, and the date of construction of many is unknown (Dunbar, 1981).

It is clearer in the Pacific than in Indonesia that the stresses on shipping antedated the oil-price shocks by several years, and had much to do with rising stevedoring costs in the ports, as also identified as a major problem in the West Indies as early as the beginning of the 1960s (Keirstead and Levitt, 1963). Stevedoring costs totaled almost half the voyage-operating costs of a Tongan ship sailing both internally and internationally in the 1960s, and in most island countries were affected by substantial increases in wages in the ports without corresponding increases in productivity (Baker, 1974). Most interisland ships are heavily crewed; thus, the crew can serve as stevedores away from the main ports. At most main ports, however, port laborers have to be used. Rising port costs precipitated major technical changes in international shipping — first palletization, then in the 1970s, the rapid intrusion of containerization in the Pacific (and also the Caribbean). For the small interisland ships, however, new technology was not available.

Freight rates in a country such as Fiji were based on the costs of wooden-hulled small ships, which formed most of the fleet until after 1960. The companies took advantage of the lower per-ton costs of the larger steel-hulled ships that they had introduced to make a useful profit. Besides, competition tended to keep freight rates stable. As costs rose, some of the older

wooden ships were forced out of the industry, but by about 1970 the operating costs of steel-hulled ships reached those of the cutters five years earlier, leading to an upward pressure on rates but with a structure now governed by the costs of the most efficient vessel. When the companies found that the early 1970s depression in the price of copra increased resistance to freight-rate increases to such a point that they could no longer make a profit, they began a rapid withdrawal, and one result was the decline in service described above (Baker, 1974).

ELEMENTS IN THE COSTS OF INTERISLAND SHIPPING

We have suggested that the cause of low productivity lay in port rather than at sea. 'Port', however, included not only the main ports with stevedores ashore, but also the outports where ships' crews handle the cargo. Couper, (1967, pp. 140-142) describes a situation still in common in the 1960s:

> '...vessels work from place to place around an island coastline as they unload small quantities of general cargo and empty copra sacks... Discharging of cargo is commonly done ... into the ship's workboats. Crew members locate the consignments in the holds, hoist them to seamen on deck and they pass the bags, drums and cases to others who are manning the workboats. The boats are rowed, or towed by launch, across the reef flat as far as possible, and the cargo is then carried by the crew to the recognized delivery zone above high water mark (at low tide about one quarter to one half mile of carriage is often involved)... The shipowner is supplying shipping, stevedoring, lighterage, towage and delivery to the consignee on the beach and he is normally fully responsible for the goods until they are landed above high water mark.'

Under these circumstances, ships spent and often still spend much more than half their time in port or at anchorage. The main ports, where shore facilities are available, are often so crowded that longer delays are caused. Caribbean schooners sailing to Trinidad in the early 1970s sometimes had to wait up to 14 days for a berth at Port-of-Spain (Brookfield, 1978). Even today, competition for trade leads to crowding of vessels in places where there is at least a jetty; one day in 1983 this writer saw three of the four regular vessels serving one main island in northeastern Fiji competing for space at the one jetty. At Sunda Kelapa (Jakarta), in the mid-1970s, 'the quay length remains quite inadequate for the number of *prahus* needing to unload timber cargoes, necessitating queuing and long waiting times outside the port' (Dick, 1978, p. 248).

Because of the need for stevedores, crews on interisland ships are larger. The government-built and subsidized ship now serving the Lau group of Fiji carries a crew of 27 for its 340 dwt and often carries no more than 60 tons of general cargo outward. Around 1970, actual crew costs of one steel-hulled interisland ship in Fiji were similar to those of an island-owned international ship three times its capacity (Baker, 1974). In Fiji in 1983, some 500 to 600 people were employed at sea on a fleet of 58 commercial vessels totaling 5,364 dwt (8,471 gross registered tons), much the same crew complement as 20 years ago although spread among more ships (Couper, 1967). This labor-intensive operation is characteristic of interisland shipping in all its forms. A 100-ton *prahu* would carry a crew of 18 (Dick, 1975), whereas in Vanuatu in 1978/79 a fleet of 45 vessels with a combined gross registered tonnage of 3,416 employed 364 at sea; the four largest vessels employing 104 persons for 1,557 gross registered tons (Dunbar, 1981). While numbers are less on the larger ships than on the smaller, it is at a high level throughout the business. The contrast with crews of 24 on 30,000-ton vessels in the oceanic trades, being reduced to fewer than 15 on the newest German designs, is extreme. Given the mode of cargo handling it is difficult to make substantial reductions, though the evidence suggests that some reductions have been achieved.

This situation is aggravated by the widespread over-tonnaging that characterizes interisland shipping. On some Pacific island trades, the tonnage available is estimated at more than double the cargo-handling task. The resulting competition certainly has a lowering effect on freight rates, at least in the cargo-rich areas that attract the heaviest service in these circumstances. However, some of the over-tonnaging may be more apparent than real, for it is due partly to imbalance of outward and inward cargoes and partly to the socially necessary provision of services to areas lean in cargo. Dunbar, (1981), believes that the latter is the main reason for the 40 per cent over-tonnaging that she calculated in Vanuatu in 1978. However, there is little doubt that the efforts made to improve productivity through the reduction of calls have increased the over-tonnaging problem on some island trades, since there has not been a corresponding reduction in the number of vessels. Moreover, one important social function has been greatly diminished in recent years because of the shift of a large part of passenger traffic to the air, and it has had an important effect on revenue.

Passenger traffic contributed from five per cent to as much as 50 per cent of total revenue on different island regions in the 1960s. Even in Indonesia the higher-paying sector of the passenger business has been almost entirely lost, and in the Pacific and the Caribbean the rapid development of aviation has deprived interisland shipping of a high proportion of its former passenger business. Rising fuel costs have had a greater proportional

effect on air than on sea fares but have done little to check the loss of sailing passengers. In the Pacific and elsewhere, not even the recent introduction of ferries with air-conditioned lounges and video programs has recaptured much of the business, perhaps partly because of greatly inferior terminal connections.

Since passenger revenue was obtained without substantial additional cost, especially in the case of deck passengers, this loss has had a serious effect on profitability. It may have been critical to the disappearance of the East Caribbean schooners. Collectively, over-tonnaging and the loss of passenger revenue have made it increasingly difficult for shipowners to afford adequate maintenance and repairs, the cost of which has risen steeply. The pressure to improve productivity has become severe, and given the difficulty of reducing turnaround time this has been translated into a pressure for faster service, the better to compete for lean demand. Almost all the changes that have taken place, both within the motor only area and between sail and motor, seem to have led in this direction. But at the same time, areas so lean in cargo as not to attract competition, even in a situation of general over-tonnaging, have tended to receive worse service than before, and in some cases there would have been a total loss of service but for government intervention.

If we seek a single common element in all this, it must lie in the need for greater productivity to meet rising costs and constrained revenues. Greater productivity has been sought through larger vessels, operating between fewer places, and improvements in cargo handling. Weaker elements disappeared, as in the Caribbean; suffered high turnover but continued to operate very irregularly for social reasons, as in the Pacific; or were relegated to more peripheral sectors, as seems possibly to have happened in Indonesia. The larger gaps that emerged in the Pacific were filled by government services operating without close cost control, and in Indonesia a government-supported program of motorization has improved operating efficiency. Greater reliance on freight-forwarding agencies ashore and further elimination of 'informal sector' operation characterized the changing situation in Indonesia and the Caribbean. In the Pacific, 'informal sector' operation had disappeared at an earlier date, but a few new island-owned ships that emerged to fill service gaps and that used informal methods of cargo acquisition mostly failed (for example, Bayliss-Smith, 1978). The signs varied somewhat to suit the conditions of each region, but they all seemed to point in much the same direction.

SOME ASPECTS OF THE PRESENT SITUATION

A further rationalization of international container shipping services is in progress, with a move toward node ports and feeder systems. This move is likely to place the three-island regions we are examining much more firmly in the domain of feeder services. The same move is, however, likely to result in a rising demand for small container or multipurpose ships and is not likely to halt the deeper penetration of new cargo handling methods into the system. Already, by 1980/81, containers on trailers were being barged to small-island ports in the Caribbean, where they were being unloaded onto wooden jetties designed for a two-ton axle load with inevitable consequences for future re-equipment. As far as the export and import trades are concerned, there is every reason to reduce the number of transhipment points and to eliminate break-bulk if rationalization is not to lead to rising costs of imports and lower returns from exports. These wider conditions will have a major effect on the demands placed on interisland fleets (Brookfield, 1980).

There also seems little reason to expect any diminution in the rate at which interisland passenger traffic is transferring to the air, except where speed and comfort can be supplied at reasonable cost, such as provided by ferries and roll-on roll-off vessels where a price is paid for speed and convenience. The old-fashioned deck passenger vessel will remain so long as the poor need to travel, but this is no recipe for the future. The value of regularity and reliability has been firmly established, but the cost of providing the sort of service that is demanded is high and competition is keen wherever there is significant traffic.

On high-volume routes, there is little reason to doubt that the vessels demanded by the new developments will be supplied and will be adopted. The growing use of roll-on roll-off vessels makes this clear. On low-volume routes, however, it is a bold entrepreneur who will innovate, and the rate of failure is likely to be high. There is a large area in which ancient shipping modes have been replaced only by unsatisfactory modes. Large private companies, if ever they were in this area, have tended to withdraw in favor of smaller companies. Yet, there is strong pressure for aid funds and the public sector to leave shipping to private enterprise. The question therefore arises whether the sort of private enterprise likely to occupy the low-volume, low-paying niches in the system will be able to provide service at a level that will prevent the further marginalization of island areas far from the node ports and the reduction of their ability to participate in the economic and social benefits of development.

The particular point to be made is that the present situation is inevitably transitory. Elimination of the last vestiges of old-fashioned pure sail now seems only a matter of time. Except in Indonesia, however, the sort of

operation that is taking its place relies on the temporary availability of a class of second-hand ships driven from other trades by innovation. The next generation of second-hand ships will be more costly specialized vessels, requiring the adoption of new cargo-handling methods for their economic use. There is a great need for innovation in interisland shipping, yet the pages of the maritime journals are almost devoid of any mention of this area. In writing of needs in relation to means, I mentioned not long ago the need to bring the door-to-door concept through from the main port to the island landing, employing size-breakdown of the container concept and a range of shipping innovations such as the landing craft and the amphibious lighter. I went on (Brookfield, 1984, pp. 76-77):

> 'In maritime development policy for the Third World it would now be advantageous to cease resistance to innovation, and to seek means of employment of innovations in new combination so as to make the door-to-door concept of universal application. The social implications... need not be deleterious. Much worse...are the implications of allowing large areas of many nations' transport systems to rely on inefficient older systems, using antiquated equipment under an increasing cost penalty... Undoubtedly the universal spread of containerization to all points capable of being reached by any type of cargo-carrying vehicle would constitute a revolution, but the present 'revolution' in areas without ports is the accelerated marginalization of large regions and large numbers of people.'

I do not go back on these statements. I believe the need for new transport equipment, a new configuration, and a new concept of the role of the state in transport infrastructure at sea as well as on land to be urgent. I do not believe that private enterprise can, or should be asked to, do the whole job. My foregoing analysis of some recent trends serves, however, to provide a focus for seeking a role for the sail-motor concept in any new system of sea transport that might emerge in and for island regions.

IMPROVING PRODUCTIVITY IN INTERISLAND SHIPPING

A Summary of the Situation

The historical treatment adopted in the preceding analysis has shown that interisland shipping has generally tended to remain apart from trends in world shipping or, if it does follow trends, it does so with a substantial

time lag. Two basic problems persist, namely, slow turnaround time and high manning levels. These problems have been eased significantly only where roll-on roll-off (or car ferry) operation has been introduced or where tug-and-barge operation is possible. Since these are confined to major links and to relatively sheltered waters, respectively, a large area of interisland shipping remains without much significant innovation.

During the past 25 years, the major change has been the replacement of wooden-hulled ships (with or without sail) with second-hand steel-hulled vessels made available by their displacement from coasting trades elsewhere in the world, usually at low cost and sometimes at distress prices. A certain amount of new building has supplemented this supply, but most of it is of conventional break-bulk ships. We have suggested that the main attraction of such vessels, apart from their low cost, has been improved speed and regularity of service between ports backed up by a fair amount of new wharf construction, although not in all areas. Some improvement in turnaround time at main ports has aggravated the problem of over-tonnaging; almost all the new ships also have derricks. However, without wharves, this feature has led to only limited improvement in ship turnaround time at many outports, and the problem of high manning levels persists. Most ships still spend at least as long in port as at sea. This remains a binding constraint on profitability.

Fuel Costs and Their Significance

The question of fuel costs has been kept in the background up to this point in order to permit analysis of the continuity of change in interisland shipping, change that has included the replacement of pure sail by sail-motor, and of sail-motor by pure motor, in different regions at times that have extended right through periods of low and high fuel prices alike. Almost all the trends of the 1970s and 1980s, analyzed earlier, will have increased fuel consumption per ton of cargo carried in all regions. Moreover, there is only limited indication that efficiency of fuel use in relation to capacity has been a major factor in either ship selection or operation until recently. Even some vessels of post-1973 construction have very fuel-hungry engines. Around 1980, a few such ships were taken out of service. In Fiji, private shipowners offered the chance to buy newer government vessels have looked askance at some because of their high fuel consumption in relation to earning capacity, but this is recent.

It is extremely difficult to establish the significance of rising fuel costs for the operation of interisland ships. Data are scanty and depend for the most part on single ship information. Comparisons between ships and between dates are influenced not only by the nature of the ships compared

but also by the manner in which they are operated. This is clear from the following expansion in Table 1 of Mr. MacAlister's comparison, in his paper, of single-ship data from Fiji in 1971 and 1980, to include data from a Tongan interisland vessel in 1971/72, from Baker (1974):

Table 1
A Comparison of Single Ship Operating Costs

	Fiji 1971		Fiji 1980		Tonga 1971-72	
	%	%[a]	%	%[a]	%	%[a]
A. Variable Costs						
Cargo handling	19	22	23	25	1	1
Port expenses	1	1	1	1	1	1
Bunker fuel	6	7	14	16	17	23
B. Fixed Costs						
Crew/victualling	35	40	31	34	29	40
Maintenance	18	20	10	11	20	28
Insurance	2	—	3	—	8	—
Depreciation	10	—	6	—	20	—
Management	8	9	12	13	6	8
Other	1	1	0	0	0	0
TOTAL (A + B)	100	100	100	100	100	100

a Without insurance and depreciation.

The Tongan ship was a government ship, a former Scilly Isles ferry operating a fast passenger-cargo service between main island groups and using its own crew for almost all stevedoring activities. It had more sea time than the comparative Fijian vessel in 1971, which was a regular cargo-passenger ship operating commercially in the northern part of the Fiji group. The Fijian ship for 1980 may well have had more sea time than the 1971 vessel. It is therefore wrong to draw firm conclusions from comparisons of this order.

There is, however, no doubt that the sharp increases in the real cost of marine fuel from 1973 to 1975 and from 1979 to 1982 had a marked effect on operating costs at sea, an effect aggravated by greater vessel use wherever this has been achieved. Savings from 20 per cent to 30 per cent in fuel costs by sail-motor operation without significant reduction in cruising speed, or of up to 50 per cent with a severe loss of cruising speed, might make a difference of about 5 per cent to up to 10 per cent in total operating costs, depending on the mode of operation, although this would be offset by some increase in maintenance costs. The use of more economical engines might result in a comparable degree of reduction with or without sail assistance.

Crew and Cargo-handling Costs

Crew and cargo-handling costs have risen by less than the costs of marine fuel in most island regions, but have nonetheless risen substantially. For reasons we have seen, both need to be considered together in interisland shipping, and this is a fundamental difference between interisland and international shipping, where in the latter, the very high costs of cargo-handling were the main cause of the cargo-handling revolution of the 1960s. The re-equipment of the interisland core fleets with steel-hulled ships since 1960 made mechanical lifting capability more available, thereby somewhat improving productivity. The vessel serving the Lau group of Fiji, for example, carries four large workboats aboard and handles cargo and passengers so expeditiously that an island call may take as little as three or four hours, rather than a whole day or more, unlike the older ships whose operations were all manual. With a maximum speed of almost 15 knots, this ship can often serve two islands in a day and can position itself at daybreak to keep waste of working time to the minimum. Even so, and even though it almost always returns to Suva fully laden, its high crew costs and large fuel bill, coupled with its small outward cargo, ensure that it operates at a loss. Ships like the one costed for 1971 in the foregoing table achieved similarly good performance by using workboats to go ahead of the ship along island shores, so that the ship itself experienced minimum delay (Baker, 1974). However, this cannot be achieved without a large crew.

Labor-intensive methods of cargo handling may be economically feasible where labor is abundant and cheap (nowadays it is neither in the Pacific). Even so, the resulting delays mean that a high proportion of the total operating costs of the ship are incurred in port. The greater the fixed costs of the ship, the less feasible labor-intensive methods become, and as Pacific ships age, efforts have been made to reduce crews, as the table shows, and to reduce the number of calls so that more of the burden of collection and

distribution is thrown onto the customers ashore. In an island region there are limits to this cost reduction strategy, quite apart from its social cost, since an additional freight charge is placed on the producers who often cannot meet it. For copra producers in parts of Fiji this additional cost may be $10 or even $20 per ton.

For the shipowners, however, the position is not unlike that confronting international shipowners in the face of mounting port costs in the 1960s, when from 60 per cent to 85 per cent of total costs were incurred in port (UNCTAD, 1972). Insofar as the above figures suggest that the interisland cost structure may not be that bad, there is also the fact that unnecessarily large crews are carried during sea passages, to all intents and purposes a 'port cost' carried at sea between ports. Although the use of sail might make some productive use of the additional crew, it is a fairly solid argument that a reduction in the crew would achieve greater economies. If, then, modern sail is designed with labor economy clearly to the fore, should not its application in interisland shipping go *pari passu* with other measures designed to improve efficiency? And is it not logical that improvements in cargo-handling efficiency come first? Moreover, if this can be done, sea time will increase proportionately, and sail assist will have greater economic value.

Need for Integrated Approaches

It is perhaps only in Indonesia, where INDOSAIL was conceived essentially as a revolutionary redesign of the *prahu,* and like the *prahu* operates as a motor-assisted sailing vessel but in a far more efficient manner, that the sort of high-crewed operation that we have discussed can continue to be contemplated well into the future. Even for INDOSAIL, present designs do not seem to adequately allow for the sort of workboat operation that would greatly improve its port time in places where it cannot berth against a wharf; there seems to be no provision for the carriage of such workboats on deck beneath the sails. Elsewhere, the need is for a more radical modification of ship design as a whole, coupled with a new approach to the technology of interisland shipping.

Cargo-handling costs can be reduced by means both internal and external to the ship. If we start from the assumption that interisland ships must serve some or many places where they cannot berth alongside a wharf, it remains true that a substantial proportion of such places can be approached closely enough to permit landing over a bow-ramp. For this reason, a seaworthy, sharp-nosed landing-craft design is widely regarded as the most appropriate for the re-equipment of interisland fleets (Brookfield, 1980). Where this cannot be done, and even where it can, an amphibious landing craft of which the obvious prototype is the World War II DUKW could ferry cargo and passengers between ship and shore. Very small, simple landing craft are an alternative. Such vehicles could be shore-based, which would greatly reduce the need for workboat operation. Cargo could be more readily unitized, mechanical handling more readily be adopted, and a good part of the job done on wheels. All this would be entirely feasible within the limits of known technology. The effect would be a substantial reduction in both turnaround time and manning levels.

Thus, to externalize some of the problems of interisland ships would demand a substantial program of re-equipment ashore as well as at sea. Use of landing-craft designs would make more difficult, though not impossible, the fitting of an auxiliary sail to achieve fuel economies at sea. What is perhaps needed is a new and smaller form of the multipurpose ship developed in Europe, able to work both at wharves and ramps or away from them, able to load both over the side and through the bow, and able to interface both with shore-based lighters or small, locally-based feeder ships and with workboats of its own. Because such vessels would achieve much higher levels of sea time, the design of suitable rigs for use of soft sails, without any need for computers aboard to manage them would achieve greater operating economies than would the fitting of sails onto conventional craft.

This, however, would take time, and it would also require major investment in the development of standard designs capable of large-scale production. Nor would such ships come cheaply. It is not something that can be expected in the short run. Meanwhile, what does seem to be both possible and necessary is the development of shore-based lighterage systems as a cheaper and more widely applicable alternative or addition to the construction of wharves, coupled with the refitting of interisland ships to handle unitized cargo in small modules. This seems to be the first road toward improving efficiency and toward bringing deep-sea innovations into the domain of interisland shipping at an appropriate reduction in scale.

CONCLUSIONS

It is perhaps advisable to divide the problem of interisland shipping into parts. There are certain areas in which there seems no place at all for sail. These are where the direction is toward roll-on roll-off operations linking road systems at the best possible speed, and some coastal and reef-bound areas where navigation conditions are such that sail can be used for only a very small part of total voyage time. There are also areas in which slow speeds are no problem, in which motor-assisted sailing ships can provide an entirely adequate and reliable service. Here the INDOSAIL model,

modified to improve its cargo-handling methods, would seem to provide the large fuel savings that would make longer voyage times entirely acceptable. Between these two situations is a large area in which higher service speeds are needed to improve the ability to time landfalls according to the state of tide and time of day, as well as to provide adequate service with fewer ships. In this area, the main need is to carry the unitized-cargo concept forward as far as possible into the trading system, thus reducing crew costs, while benefiting from sail during the larger part of total voyage times spent at sea. This area seems to offer the greatest challenge to designs, both for retrofitting and for new building. Most of the Pacific region, other than the traffic between large roaded islands and the services to truly outlying small islands would seem to fall into this third group. As does the Caribbean, perhaps much of Indonesia also.

Finally, the emphasis placed on crewing and cargo handling in this paper rather than fuel costs, arises from an analysis of priorities, not from any sense of opposition between different sets of innovations. Interisland shipping has been consistently slow in its adoption of innovation, which is why sail lingered in this area for so long after it had vanished from the high seas. Despite the still recent experience of sail in the island regions, and its vigorous survival in some (Indonesia in particular might suggest this as a priority area for the reintroduction of sail in new forms), a larger and more serious lag has to be overcome first. The emphasis first on cargo handling and then on manning levels in the modernization of the deep-sea fleets is only slowly extending into the interisland area. Although there have been changes designed to improve both cargo handling and manning levels, they face limitations that can be overcome only by major technological changes. If these necessary changes can be combined with the reintroduction of sail, then interisland shipping might, for once in its history, take a very major leap forward. The papers in this collection suggest that such a leap forward just might be possible.

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QUESTIONS AND ANSWERS

Q: Most of the problems you have described apply to the Cook Islands. There are vessels in the Cook Islands which are now approaching the end of their life. It will be very expensive to buy new vessels. Also, the cost of capitalization will be expensive; at approximately US$4,000 a day, it will be more than the operating cost per day. (Mr. D. Silk)

A: There is no easy answer. Maybe ten years of life could be gained by rebuilding some parts of the vessel. The situation is an extremely serious one. Greater local shipbuilding could be an answer but only if you deal with very simple designs. Very soft loans might also help, just as help from governments would.

Q: Containerization is a significant dimension of internal trade. In your view, would it be desirable to have internal trade retained by each country's national operatives? (Mr. A. B. Thakur)

A: It really depends on the size of the country. Indonesia can retain its internal trade very readily, but a country like Fiji has a limited area of internal trade. A question really arises with very small Pacific island countries whether or not a feeder service runs through countries and serves more than one.

Q: I would like to clarify your position regarding the benefit of sail-assistance. Is it your view that it will be of benefit only if there was increased sea time? (Mr. P. MacDonnell)

A: This is so. I'd like to point out that there is a great deal of excess tonnage capacity provided by interisland fleets. In Fiji, for instance, by nearly 100 per cent.

Q: Can the landing craft type of vessel make use of a sail system? This would be relevant to the Philippines situation where landing craft are used because of the lack of port facilities. Are any drawings or designs available for fitting sails into this type of vessel?
(Mr. R. A. Oliveros)

A: Anything with a side loading would be suitable for sail assistance. I am not aware of any drawings or designs of sail for landing craft but there might be one on the drawing board. Mr. MacAlister may know.

A: There is no inherent reason why landing craft cannot be fitted with sail. In fact, we did look at this type of craft in Fiji under the ADB Project. The problem is that simple sail solutions are much more difficult for vessels where you cannot use the center sections of the vessel. In this case, rigid sail systems could be introduced.
(Mr. R. G. MacAlister)

Q: A number of aspects you have mentioned are not restricted to interisland shipping. For instance, loss of passenger trade is felt worldwide. I would like to say that domestic shipping is very often affected by developments and action of a political nature. These events have put back domestic shipping a great deal. We can perhaps think of how operators can come together for economies of scale.
(Capt. E. Corten)

A: This is a difficult situation because during the days of the multinational shipping companies, international boundaries were not that well defined.

Q: You have referred to a number of causes for the difficulties which have particularly affected interisland shipping, for example, income squeeze, due among other reasons, to loss of passengers. Is it not so that the whole liner trade worldwide has been affected by an income squeeze? While international shipping countered by employing ever more efficient new vessels requiring ever increasing outlays, interisland shipping had no fleet renewal programs. While international shipping lost 100 per cent of its passenger trade to airlines, interisland shipping today still carries a substantial number of passengers. One could say that they did better. (Capt. E. Corten)

A: The question begins with a statement with which one can only agree, except that the remaining passenger traffic of interisland shipping derives largely from the social-service function of these ships, so that in at least some cases, vessels sail because there are passengers to carry whether or not there is sufficient cargo. The passenger requirement which remains therefore contributes to the over-tonnaging problem of so many interisland fleets. This is especially so since a high proportion of the remaining passenger traffic consists of deck passengers who contribute much less to revenue than the cabin passenger traffic which has largely been lost.

The other part of the statement, that there have been no fleet renewal programs in interisland shipping is only true in part. The replacement of wooden ships and older steel-hulled ships by second-hand tonnage imported from developed country coasting trades has been a partial renewal program and, as I have shown, it has led to some improvements in cargo-handling capacity. However, it has been rather like the sort of hand-down renewal program with which families reclothe their younger children, and the maintenance costs of the handed down equipment tend to be high, and suitability tends to be low. Nonetheless, this element of 'fleet renewal' should not be neglected; the real question is 'what comes next?'

Q: I have missed any reference to political causes for the unfortunate state of affairs, to name some:

(a) Emergence of small independent sovereign nations, fragmenting existing interisland sea communication systems into national subsystems with different aspirations;

(b) Influence of government policy and national priority setting; and

(c) Implementation of development programs which are detrimental to cargo-support or load-factor efficiency. (Capt. E. Corten)

A: Captain Corten's question is of major significance. The political aspect was played down in both the Conference presentation and written paper, though I have raised it in other publications. The tendency to internalize trade within political units goes back to the colonial period in the Pacific, with the principal exception only of a fairly substantial penetration of the Vanuatu trade from New Caledonia in the condominium period, when the islands were administered jointly by Britain and France. The origin lay in the declaration of ports of entry, in which it seems very likely that the trading companies exerted pressure on colonial governments to concentrate foreign trade, over which they could therefore obtain firmer control. To a large degree, the pattern was already established by 1900 and has changed only a little since. Witness, for example, the many years that it has taken to provide a port of entry in Vanua Levu, Fiji.

The effect of this is apparent enough in the recent past. Witness, for example, a subsidized operation providing a service from Suva to Rotuma without continuing to Tuvalu, while a separate (and separately

subsidized) service carries the small quantity of Tuvalu copra to Fiji for milling. Or, the fact that Southern Lau is served from Suva and not Nuku'alofa, which is much closer. Or, that Wallis and Futuna are connected only with Noumea. It is not much less absurd in cost terms that the whole of eastern Indonesia lacks a foreign-entry port further east than Ujung Pandang. The situation is rather different in the Caribbean, where the extreme political fragmentation has prevented the emergence of such distortions, although it has greatly added to the costs (and smuggling opportunities) of interisland trade.

In the future, a much greater cost penalty may be suffered if intercountry and interisland services are not integrated in the Pacific. All that is needed is one country to set up a successful pivotal port with full container capacity (it could be Papua New Guinea, and it is not likely to be anywhere further south if a round-the-world service is successfully to be attracted), and the whole region might come to be served by feederships. A double transhipment would then become the fate of most island traffic, instead of only small parts of it as at present. One misses any thought of providing or equipping for through services in any of the national plans.

The other issue of Government policy is addressed briefly in the paper, which is the need for a different approach to sea transport, one which would recognize that while the sea is a 'free' road, its vehicles are necessarily larger and more costly to operate than road vehicles, while the rewards tend to be smaller. This issue is discussed at length by me in Chapter 10 of a forthcoming book (T. P. Bayliss-Smith, R. D. Bedford, H. C. Brookfield and M. Latham, *Islands, Islanders and the World: The Colonial and Post-Colonial Experience of Eastern Fiji*, Cambridge, University Press, 1986 or 1987) and more briefly in a recent survey of the coconut industry in Fiji, in *Land, Cane and Coconuts: Paper on the Rural Economy of Fiji*, by H. C. Brookfield, F. Ellis and R. G. Ward, Department of Human Geography Publication No. 17, Canberra, Australian National University, 1985.

I doubt, however, if I can do much to deter governments from sectoral thinking in which transport is regarded as somehow separate from the task which it has to perform. This is unlikely while such bodies as the World Bank, the South Pacific Bureau for Economic Development (SPEC), the Asian Development Bank and UN-ESCAP, follow a similar approach. Sea transport does not receive a high priority at the within-country level, by contrast with the massive investment in overseas terminal connections, at least in Asia, if not in the Pacific.

The larger question of development programs which are detrimental to cargo support and load-factor efficiency is also addressed in the two sources cited above, at least for Fiji but with implications for other areas. Decentralization of milling in the coconut industry, now a widespread phenomenon, has obvious implications for load factors on interisland ships, or alternatively requires a new set of approaches. Perhaps more than this, national self-sufficiency programs in particular commodities are inimical to the prospects of regional trade. This is outstandingly so in the Caribbean, but one wonders also at the cost effectiveness of developing a small sugar industry in Papua New Guinea while Fiji has to seek remote markets for most of its very efficiently grown output. This sort of question has been discussed many times in many contexts, and one despairs of the prospects for any change.

To answer more fully than this would require another paper, perhaps even several papers. But the questions which Captain Corten asks are certainly important, and greatly affect the future operational environment of shipping in island regions.

Compatibility of New Sail Techniques with Present Interisland Shipping Practices in the Asia/Pacific Region, An Indonesian Case*

Marah S. M. Harahap**

INTRODUCTION

Indonesia is an archipelago of well over 13,000 islands. The sea area which embraces Indonesia is almost seven million sq km, which is approximately 3.5 times the total land area. Some 10 per cent of the islands are inhabited by a population of over 160 million, 60 per cent of which live on the island of Java which is only the fifth largest island in the archipelago, comprising about seven per cent of the total land area of the country.

To overcome the uneven distribution of population, support the development of all parts of the country and increase interisland trade, a network of reliable interisland sea transport is needed.

In the course of several Five-year Development Plans, the Government has improved the interisland sea transport system by increasing the transport capacity, rehabilitating navigational and port facilities, improving the integration of shipping routes and so forth. However, to fulfill the future requirements for sea transportation these undertakings are not sufficient. Other efforts are needed, including the development of ship types more suitable to conditions in Indonesia.

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* While there is inevitably some overlap between this paper and that of Mr. Suleman Wiriadidjaja and Mr. P. Schenzle, this paper sets out the context of the INDOSAIL Project in greater detail. During the Conference it provided an introduction to the Workshop sessions where delegates considered potential sail-motor applications in terms of their own shipping environments.

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At present, the interisland sea transport network is divided into five different shipping categories as follows:

(i) Regular liner services, which link the main ports on fixed routes, using motor ships of between 500 and 3,000 deadweight tons (dwt);

(ii) Local shipping, which serves ports other than the main ports on fixed routes, using motor ships of 100 to 600 dwt;

(iii) People's shipping, which substantially make interisland voyages without fixed routes, using traditional sailing ships made of wood, or motorized sailing ships of 100 to 200 dwt;

(iv) Pioneer shipping, which serves isolated remote areas on fixed routes. Commercially, this shipping sector is not profitable; its main target is to open up such areas; and

(v) Special shipping, which is operated by industrial enterprises to transport their own products, both on regular and nonregular routes. The types of vessels used by this kind of shipping include oil tankers, log carriers, bulk cargo carriers, etc.

The distribution of routes, the allocation of ships and their tonnage for regular liner services, local shipping and pioneer shipping throughout the country, are determined by the Government, taking into consideration the development and growth of different areas. At present, there are four gateway ports for international shipping, 14 collector ports and 25 distributor ports determined by the Government as centers for the development of their hinterlands.

The national fleet is being developed both by the Government and by domestic private enterprise. Joint enterprise in developing the national fleet with foreign investors is permitted only for specified routes.

The cargoes carried by the regular liners, local, people's and pioneer fleets are usually general cargoes. Conventional break-bulk methods are predominantly used. Transportation by unitized methods, that is, with containers and pallets, is still extremely limited. This is because there are very few ports that have the proper facilities for container handling and the vessels in use are still of the conventional type.

APPROACH

The use of fuel oil for ships increased rapidly after oil replaced coal. Today, the cost of fuel oil is the largest cost component (approximately 30 per cent) of ships' operating costs. Since the fuel oil crises and due to the growing scarcity of fuel oil in the future, experts concerned with ship design have been debating whether the time has come when wind power can be used efficiently and effectively for ships' propulsion.

In 1979, Indonesia's Minister for Research and Technology introduced the idea of cooperation between Indonesia and West Germany in the development of commercial sailing ships for the future interisland sea transport requirements in Indonesia.

The present program for the development of commercial sailing ships is not intended as a replacement of the traditional sailing ships but as a supplementary element for coastal and interisland shipping. The commercial sailing ships to be developed cannot be compared with the traditional sailing ships that are still operating or with the classical sailing ships that once existed. This is because of differences in the concept of operation, in the materials and the technology to be used.

For this reason, there is not a single sailing vessel in the world that can be used as a concrete guide for design. The commercial sailing ship must be designed on the basis of the conditions determined by the operational environment of the present and of the future.

To fulfill the conditions as a supplementary element for coastal and interisland shipping, the commercial sailing ship must be designed on the basis of the following criteria:

(i) The load capacity and the size of the vessel must be proportional and suited to coastal and interisland shipping;

(ii) The propulsion power should be a combination of wind and motor;

(iii) The ship must be capable of loading and unloading cargoes efficiently;

(iv) The ship must be simple, safe and convenient to operate; and

(v) The vessel must have sailing schedules and speeds that can be relied upon.

In view of the above criteria, the ship to be developed constitutes the prototype of a modern commercial sailing ship, capable of competing in almost all respects, except speed, with motor ships of the same size.

LOAD CAPACITY AND SIZE OF VESSEL

The greater part of the motor ships serving interisland sailing routes (the regular liner services) are general cargo motor ships exceeding 500 dwt.

For the experimental project, the capacity of the prototype commercial sailing ship has been fixed between 800 and 2,500 dwt. The other dimensions of the ship, such as the draft, mast height, rig system, general arrangement and so forth, form limitations that need careful consideration, so that the stability and other technical characteristics of the ship, and also the price and operational costs, can be optimized.

COMBINED MOTOR AND SAIL PROPULSION

At present, the development and application of sails for commercial ships is based on two different concepts of application that influence the level at which fuel oil is used and the function of the sails to propel the ship. The two basic concepts are:

(i) Development of the sail as auxiliary power

Under this concept, the engines are still the main source of propulsion. During advantageous wind conditions, sails will be used in combination with the engines. Synchronization of power, produced by engines and sail together, will produce the required propulsion at specified speeds. This concept allows fuel oil savings of 10 to 20 per cent.

(ii) Development of the sail as main power

This concept is for a sailing ship in the real sense. The engine in this type of ship functions only as auxiliary power when the ship enters or leaves port, for sailing when there is little or no wind, and under other disadvantageous weather conditions. During advantageous wind conditions, the ship will depend primarily on sails. The optimum size of the sails and the technology for operating them dominate the design features of the vessel and her machinery. The sails are designed to be as large as practically possible, with easy control for furling and unfurling while sailing. Under this concept, it is expected that there can be a saving in fuel oil of 70 to 80 per cent.

The question of which of the foregoing concepts of propulsion by combined motor and sail and, therefore, which prototype sailing ship is most suitable, depends upon the wind conditions in Indonesia and the main objective to achieve the greatest practical saving in fuel oil.

The seas of Indonesia, the Java sea in particular, are areas of light equatorial winds with weather under the influence of a monsoonal climate. Both the strength and direction of the winds can be predicted reasonably well for each season (see Figure 1). Tropical storms and typhoons practically never occur in Indonesian waters. The wind conditions are generally advantageous for sailing and enable traditional craft to sail almost the entire year round.

Considering these advantageous wind conditions, it is only proper that the second concept, for development of the sail as the main power, should be utilized for the prototype commercial sailing ship. Thus the prototype will be a sailing ship in the real sense.

CAPACITY FOR LOADING/UNLOADING CARGO

The traditional sailing ships that belong to the people's fleet have no gear for loading and unloading cargo, as do the interisland motor ships. To load and unload cargo efficiently the prototype sailing ship will have to be equipped with its own cargo gear. This is important, in view of the fact that not all ports in Indonesia have adequate loading and unloading equipment, such as cranes. The selected cargo gear will have to be of comparable performance with that of cargo motor ships of the same size. For example, the prototype sailing ship will be equipped with hatches and twin derricks at each hatch which will be designed to permit the loading of empty 40-foot ISO containers of up to five tons in weight. The derricks will also be used to load and unload pallets of bagged and other break-bulk cargo.

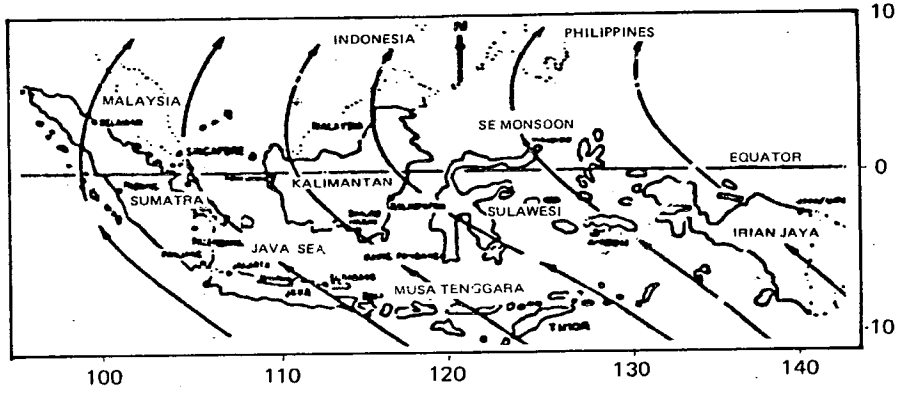
The rig will also be designed so that the hatch of the prototype commercial sailing ship can be easily reached by a cargo derrick located on another ship (for example, a 20,000 dwt ocean-going vessel) when the ships are berthed side by side. This concept will also apply to mobile cranes in ports where they are available. In addition, it will be possible to equip the vessel with side ports, stern ramps, conveyors and so forth.

SIMPLICITY AND SAFETY OF OPERATIONS AND EASE OF SHIP'S MAINTENANCE

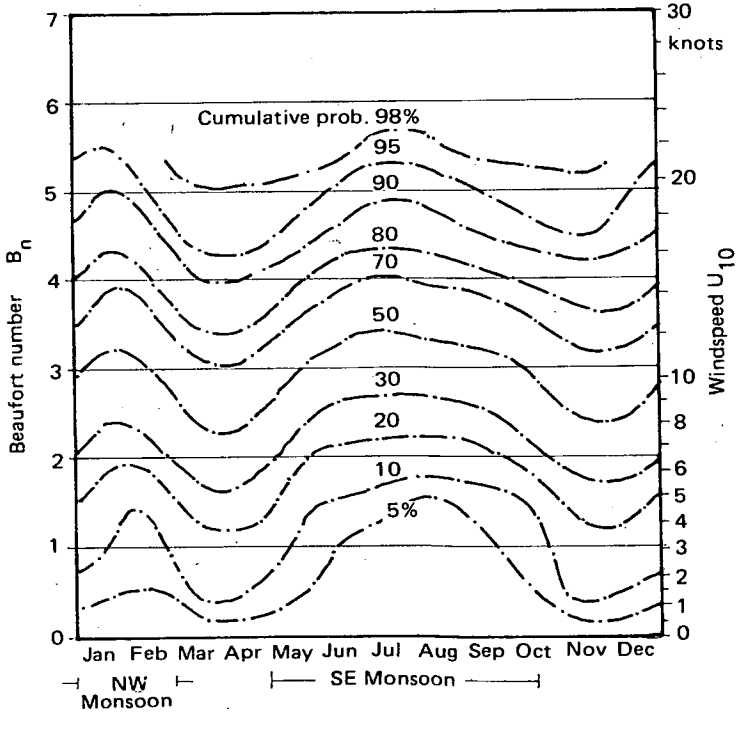
The safety of the ship's crew and of the ship itself must be ensured during operations. This can be achieved with a rig design that is not too complicated and is easy to handle and control. The sails will be operated

Figure 1

(a) South East Monsoon (July to September)



(b) Seasonal Distribution of Wind Forces in the Java Sea



mechanically, so that the required crew number will be comparable to that of a motor ship of the same size. In addition, the crew must be able to work safely and conveniently as on a motor ship. As an example, the sails will be entirely controlled from the deck to avoid the need for any of the crew to go aloft.

Ease of maintenance is another major condition for smooth operations, for the safety of the ship and for long economic life. It will be possible to achieve this by ensuring an appropriate general arrangement for the vessel and a well conceived layout of equipment.

To ensure safety in sailing, the prototype sailing ship must be equipped with modern communication and navigation equipment, as used on motor ships of similar size. It is also intended that, by providing appropriate facilities, the crew will not need to hold higher qualifications than the crew of similar motor ships.

The proposed sailing ships will also differ from traditional sailing designs in that they are to be built in accordance with ship classification society requirements. International and Indonesian Government maritime safety and pollution conventions and regulations will also be applied.

RELIABILITY OF SAILING SCHEDULES

The question will of course arise regarding the reliability of sailing schedules. Only actual operations can really provide the answer to this question. Nevertheless, with the right assumptions and approaches, the question can be answered with a reasonable level of certainty.

The winds in the Java Sea are comparatively light, but are seasonally constant. For most of the time, it can be said that the strength of the winds are suitable to propel a large area of sail and obtain the predicted sailing speed. The sailing vessel should, therefore, be able to meet estimated sailing schedules and will only need to use its auxiliary engine from time to time to ensure the desired service speed.

In the transition period between the two monsoons, when the wind is irregular, sailing speeds will be lower. Sailing schedules can be adjusted to conform with these lower speeds and the sailing ship will still be able to perform reliably, even though it has more days at sea than during either of the monsoons. To meet sailing schedules in the transitional period, economic considerations must be very carefully considered. If sailing time becomes very critical, the cost of fuel oil will be higher because the auxiliary engine will be used longer to obtain the required service speed. On the other hand, if economizing fuel consumption becomes critical, the use

of the auxiliary engine can be reduced, so that the sailing speed becomes lower and the time at sea longer.

Thus, the ability of a sailing ship to meet the planned sailing schedules is not a problem that cannot be overcome.

ECONOMIZING OPERATING COST

At present, the cost of fuel oil is the largest cost component (about 30 per cent) of the operating costs of motor ships. The prototype commercial sailing ship is designed to make the greatest possible savings in fuel oil. The question, of course, arises as to what savings in operating costs can be achieved compared with a motor ship. It is difficult to answer that question quantitatively at this stage, since certain operating cost components for the prototype commercial sailing ship cannot yet be determined, such as, maintenance and repair costs.

The operating costs of motor ships and commercial sailing ships are both influenced by the price of fuel oils. However, an increase in fuel oil price will cause the operating cost of motor ships to rise much more sharply than that of sailing ships, due to the difference in fuel oil consumption. At a certain level of fuel oil price, the operating cost for the two ship types may be the same, but at higher prices commercial sailing ships will be cheaper to operate than motor ships (see Figure 2).

EARNINGS AND CARGOES

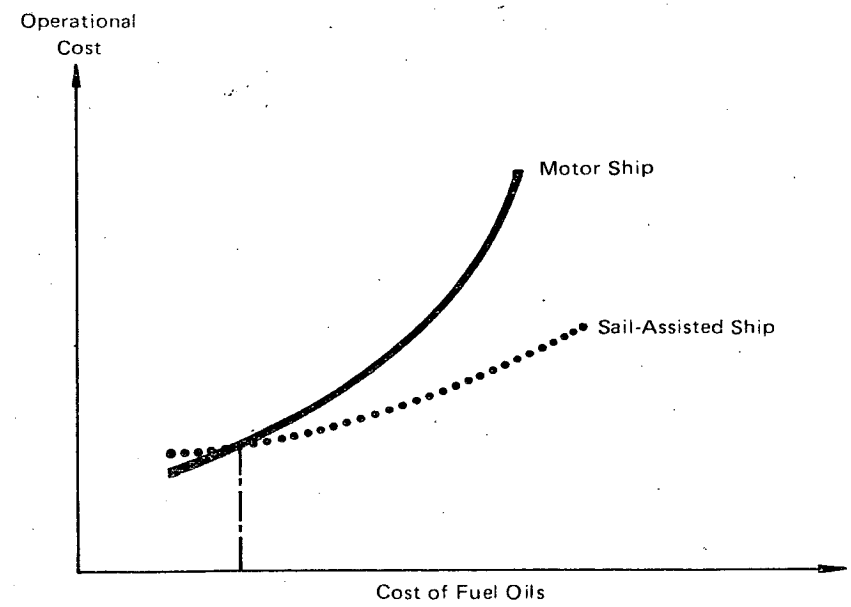
It has been said already that the prototype commercial sailing ship will be a modern vessel that will be able to compete in all fields, except speed, with motor ships of the same size. Since they will be slower this may effect the marketing value of its services, or types of cargo carried and the freight earned. Time and experience will tell how things will develop but efforts must be made to put everything in its right perspective to create the best solutions.

CONCLUSIONS

The above criteria are based on interisland shipping conditions in Indonesia. By adjusting these criteria to conform with socioeconomic and weather conditions in other countries, this concept for commercial sailing ships could also be applied to other countries in the Asia-Pacific Region, as well as in the other comparable parts of the world.

Figure 2

Relative Operating Costs for Motor Ships and Sail-Assisted Ships



The Indonesian-Federal Republic of Germany INDOSAIL Project

Suleman Wiriadidjaja and Peter Schenzle*

INTRODUCTION

In 1979 the Minister of State for Research and Technology, Prof. Dr. Ing. B.J. Habibie, initiated an Indonesian-German cooperation in the development of cargo sailing vessels for the Indonesian interisland trade. Accordingly, the bilateral research and development Project INDOSAIL was started in 1980, under the joint sponsorship of the Ministries for Research and Technology of the Republic of Indonesia and the Federal Republic of Germany.

INDOSAIL is a short-term effort towards the long-term objective of *Kapal Surya,* the Solar Ship proposed by the Indonesian Minister. While the INDOSAIL vessel is a wind-propelled ship with diesel auxiliary power, the Solar Ship will be completely independent of fossil energy by direct utilization, as well as storage, of solar energy for both auxiliary propulsion and energy supply.

The development of the project was conceived in five phases:

(i) Project definition;

(ii) Technical alternatives and rig development;

(iii) Design of a prototype ship;

(iv) Construction of the prototype by Indonesia; and

(v) Extensive trials and project evaluation.

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* Ir. Suleman Wiriadidjaja was the Conference Chairman and his background is referred to earlier. Mr. Schenzle is a naval architect and research assistant at the Hamburg Ship Model Basin. He is Project Manager of the Federal Republic of Germany team for the INDOSAIL Project.

Under the coordination of the Agency for the Assessment and Application of Technology (BPPT) Jakarta and the Hamburg Ship Model Basin (HSVA) the partners in the current phases of Design and Construction of the prototype ship are the shipyard PT. PAL Indonesia of Surabaya, Ir. Buro Weselmann of Hamburg and F. Weiss FEG of Ahrensburg.

Scientific and technical prerequisites for an efficient and labor-saving utilization of the wind for ship propulsion were developed after commercial sail declined on major world routes some 80 years ago. Therefore, traditional examples as well as modern possibilities and requirements had to be carefully examined to form the basis for a present day concept for the design of a prototype ship and rig which will be, in many aspects, an experimental system for alternative solutions.

BACKGROUND, OBJECTIVES AND SCOPE OF THE PROJECT

Background

Indonesia is an archipelago with over 13,000 islands, about 1,000 of which are inhabited. It has an area of approximately seven million sq km of seas, extending about 4,500 km east to west and over 1,500 km north to south. Under these conditions, a large fleet for sea transportation is essential, not only for the economy, but also for almost all aspects of the national life.

Petroleum is one of the chief stimulants of development in Indonesia because of its position as the largest of all sources of foreign exchange. The foreign exchange proceeds from exports of oil and natural gas composed 60 per cent to 70 per cent of Indonesia's total export earnings in the 1980s.

Although Indonesia is one of the oil-producing countries, the sharp rise in price since the early 1970s has caused an even higher opportunity cost for the use of fuel oils at home.

Indonesia is also aware that it is not appropriate, for the long term, to be dependent always on petroleum since it is a nonrenewable resource that will eventually become scarce.

Because of these considerations, there has been a growing conviction that natural resources need to be utilized wisely. Various undertakings have been started and are being carried out for this purpose. With regard to petroleum itself, refineries are being built, not only to economize on the cost of refining, which was formerly carried out abroad, but also with the aim of diversifying products, especially in the processing and utilization of heavy oils. Efforts made in other directions cover research and development of various alternative sources of energy such as water, wind, solar energy, coal and wood.

One of the projects being carried out in the field of developing alternative energy resources is research and development of the technology for motor-assisted sailing vessels, as noted in the introduction.

The use of sail has a long history and continuing importance in the interisland transport network of Indonesia (some traditional designs are shown in Figure 1). However, under the INDOSAIL Project, future development of sail in Indonesia is considered to lie in the development of a powerful, newly designed sailing vessel, able to compete with modern motor vessels in every respect except speed.

The research and development involved in the INDOSAIL/*Kapal Surya* project is therefore being carried out on the basis of design criteria, namely:

(i) Increasing added value from sea communications;

(ii) Increasing efficiency in the operation of ships;

(iii) Reducing operational costs by economizing on fuel oils;

(iv) Making the loading and unloading capacity of motor-assisted sailing vessels at least the same as that of commercial motor ships; and

(v) Developing the operational safety of motor-assisted sailing vessels to an equal level of commercial motor ships, by mechanizing the sail system, to a certain degree.

Objectives of the Project

In broad terms, the aims of the project are:

(i) To utilize wind as the chief motive power of ships, in the context of economizing fuel oils and improving the economic conditions of domestic shipping companies; and

(ii) To apply scientific progress and appropriate technology in the shipping industry.

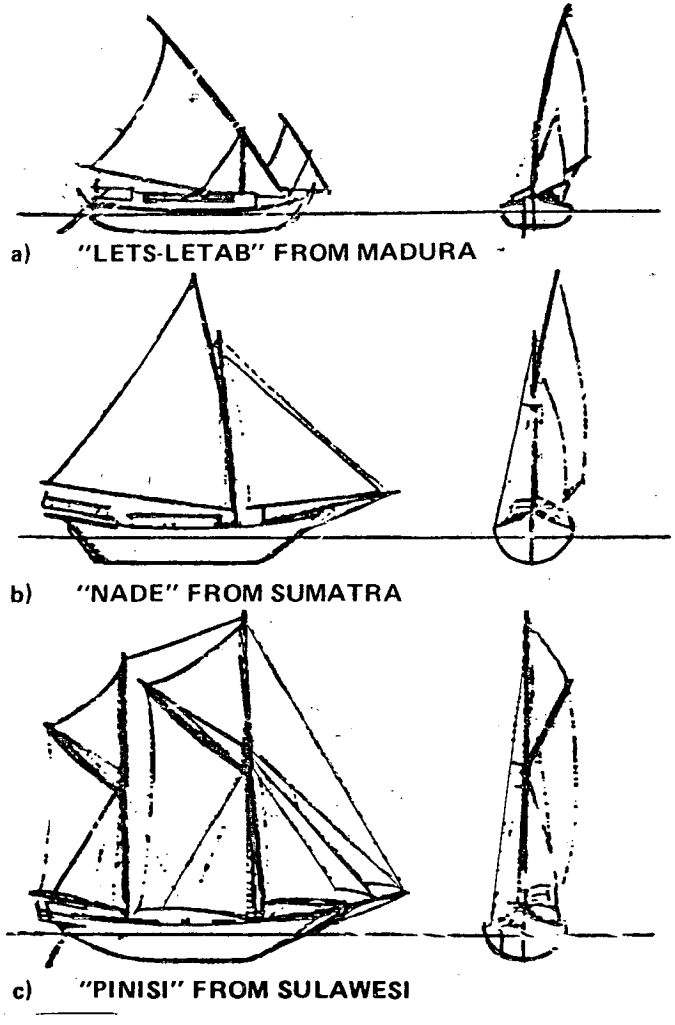
Scope of the Project

In broad terms, the research project covers the following activities:

(i) Conducting economic and technical research and evaluation in the context of environmental conditions;

Figure 1

Traditional Types of Sailing Prahus



To meet the objectives of the INDOSAIL project, the planned INDOSAIL vessel must be a powerful sailling ship able to compete in every respect but speed with modern motor ships. Thus, it is in no way comparable to the 100-200 ton dwt sailing vessels presently still operating in Indonesian waters. Nor can the future INDOSAIL vessel be modelled after the larger classical European or North American sailing vessels of the turn of this century since its operating concept and construction materials and equipments demand a different approach to rig and ship design. As a consequence of this situation there is no applicable precedent sailing ship that can serve as design guidance for development.

(ii) Carrying out laboratory research and tests and conducting trials with models;

(iii) Constructing a prototype vessel; and

(iv) Monitoring and evaluating the operation of ships.

Project activities were commenced at the beginning of 1980 on a phased basis and were planned to end in 1987.

TECHNICAL CONCEPTS FOR COASTAL AND INTERISLAND CARGO SAILING VESSELS

General Considerations

The design of a wind-propelled cargo ship is governed from the early stages by various restrictions and the need to combine or integrate several different functions. The most serious restrictions for a sailing ship are the limitations, both in air and in water, of a fluid dynamic lifting system. The limit of the ship's draft, in our case to about five meters, is due to the silt laden estuaries where most of the Indonesian ports are situated. The air draft, or mast height, is limited not only by requirements to pass under certain bridges but also by weight, stability and cost considerations. A further restriction is imposed on the rig and general arrangement of the ship by visual requirements from the wheel house, resulting in an upper limit for the position of the wheel house and a lower limit for the sail.

Hull Design

If we accept that a rig limited by height will be a multimast rig, then we will find in the very first stage of sketching the basic configuration of hull and rig that the position and spacing of masts cannot be chosen independently of the subdivision of the hull. The structural advantage of introducing the loads of masts and shrouds directly into the bulkheads is quite obvious, but at the same time the spacing of the masts determines the length of cargo holds and hatches. A simplified shroud system only in the planes of the bulkheads requires a lengthwise system of stays over the mast tops, resulting in a trapezoidal rig configuration which matches a hydrodynamically favorable trapezoidal hull outline.

If the hull of a multimast sailing ship of an ordinary commercial type, on even keel, without fin keels or center-boards, is sailing close hauled at a small drift angle, the hydrodynamic side force will develop rather close

to the stem. The latter, together with the more evenly distributed aerodynamic side force on the sails, results in a windward yawing moment which must be balanced by a permanent angle of the rudder to develop a side force similar to that on the hull. The windward yawing moment is even more serious in the heeling condition, due to an effective camber of the immersed part of the hull. This high permanent loading of the rudder would result in reduced maneuverability and increased resistance, or require an unusually big rudder. The traditional way to counteract this tendency is to shift the sail plan forward relative to the hull, as on large multimast ships with bowsprit and small mizzen sails and/or a rake of keel, increasing the draft gradually from stem to stern as on the famous schooners of the last century.

In an attempt to adapt these features to modern design principles we came up with a trapezoidal hull (Figure 2). The very raked stem has in its upper part of the function of an integrated bowsprit, shifting the sail plan forward, while its lower part is extremely cutaway to shift the hydrodynamic side force backwards.

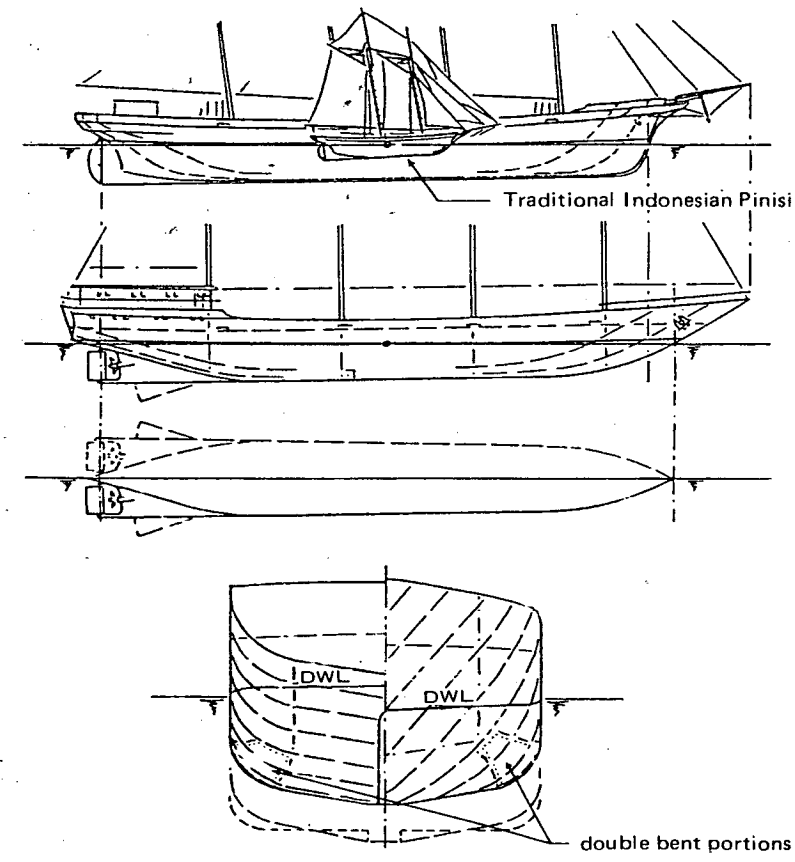
For practical reasons, the hull is designed without a rake of keel but with parallel deck and keel and with the bulkheads and masts at right angles to both. The effect of a rake of keel is simulated, instead, by a loading condition which has a stern trim of about two per cent of the length. To compensate for this angle in the accommodation area, the decks aft of the cargo space are tilted slightly upwards.

The type of the afterbody is sometimes called a 'free-flow' or 'buttock-flow' stern, with the bottom bending gently up into straight buttock lines ending at a wide transom. The advantages are low resistance, high stability and sufficient space for accommodation aft of the mizzen mast. In the stern-trim condition, the flat, narrow skeg has some effect of a fin keel at a position (well aft) where it is most required. A retractable center-board below the skeg, though favorable, was not adopted to avoid complication and damage. The lateral underwater outline of this type of hull, together with its mirror image with respect to the water plane, resembles a slender delta wing, the lift (side force) of which is proportional to the square of the maximum span (maximum draft).

The midship section is designed with a marked rise of floor and well rounded bilges, thereby reducing the wetted surface and avoiding increased resistance at significant stern-trim. An alternative midship section with the same draft and area, but with a flat bottom plus a rectangular bar keel, showed no increase in side force at small draft angles but a remarkably increased resistance when tested in the towing tank. It might be concluded that a bar keel is only worthwhile as a retrofit to increase the draft. Otherwise, a smoothly rising floor of the same total draft would be preferable.

Figure 2

Concept of the Hull Form



The simple surface of a hull of this latter type could be developed to within more than 90 per cent, with flat and cylindrical portions, without hard chines, but with two small double-bent portions at the transition between the midship bilge and the fore and aft shoulders respectively, as indicated in Figure 2.

Another important area where different functions must be taken into account is the rig, which must determine and then reconcile the optimal configuration for sail propulsion with the practical requirements of cargo handling. In this regard, extra weight and cost should be reduced and interference can be avoided by the incorporation of double functions for the masts, booms and winches, to the extent practicable. The standing rigging should leave the space between the masts as open as possible for cargo operations. The change of rigging from sailing to cargo handling, and back, should be as easy and as fast as possible.

Cargo Handling

For the handling of light cargo, requiring about two tons safe working load, a second cargo boom for each hatch that must not impair sail handling can be operated in union purchase with the sailing boom. The required single lifting capacity of the sail boom is five tons, for bundles of pipes and empty 40-foot containers on deck, etc.

The concept of sail handling is open to any degree of mechanization, remote control, or automation, as appropriate to meet present or future requirements.

The Auxiliary Engine

With regard to the auxiliary engine, as 'motor-assistance' for a real sailing ship, three main operational conditions must be considered:

(i) A low added resistance from the propeller during pure-sail propulsion;

(ii) A relatively low power requirement for a moderate minimum speed in calm weather and during port entry and departure; and

(iii) A high thrust requirement to ensure safe maneuverability in strong adverse winds and waves in restricted waters.

Since the resulting average and maximum power requirement for propulsion and for on-board energy supply may well turn out to be in the same order of magnitude, a convincing solution may be a central power plant which supplies the required energy for propulsion, light, heating and cargo handling, under every operational condition, whether for cargo handling, sailing, motor sailing, or motoring in calm. The precondition for this power plant solution is a simple and reliable diesel-electric propeller drive. Separate prime movers for propulsion and energy supply would require a higher installed power which is run, on average, at unfavorably low rating and provides less flexibility. To adequately meet the bad weather operational requirement, a large diameter, low-speed propeller is required, with about 100 per cent power reserve for high thrust. This propeller can be of fixed pitch and two-bladed, locked behind the skeg during pure sailing.

SELECTION OF AN APPROPRIATE RIG TYPE

Since the INDOSAIL vessel is expected to achieve a substantial amount of fuel savings, it will be a real 'windship', with an auxiliary propulsion engine. This requires a complete rig as a primary propulsion system and a comparatively large sail area. For the technical system there is broad variety of historical examples and modern proposals (see Figure 3). There is the possibility of a modern development on the basis of the traditional rig types used at the turn of the century. Along this line are the proposals for a stepwise mechanization and aerodynamic streamlining of the traditional square rig, as for example, via the curved yards and the roller furling of the 'Dyna Ship' to the symmetrically cambered, rigid panel sails which are used in Japan. Similar proposals for development of the fore and aft rig lead via the soft cambered airfoil of the 'Princeton sailwing' to the 'wingsail', a rigid airfoil with trailing edge flaps.

Typical development steps are:

(i) Aerodynamic shaping of soft sails and their leading edges;

(ii) Mechanized roller reefing and sail handling;

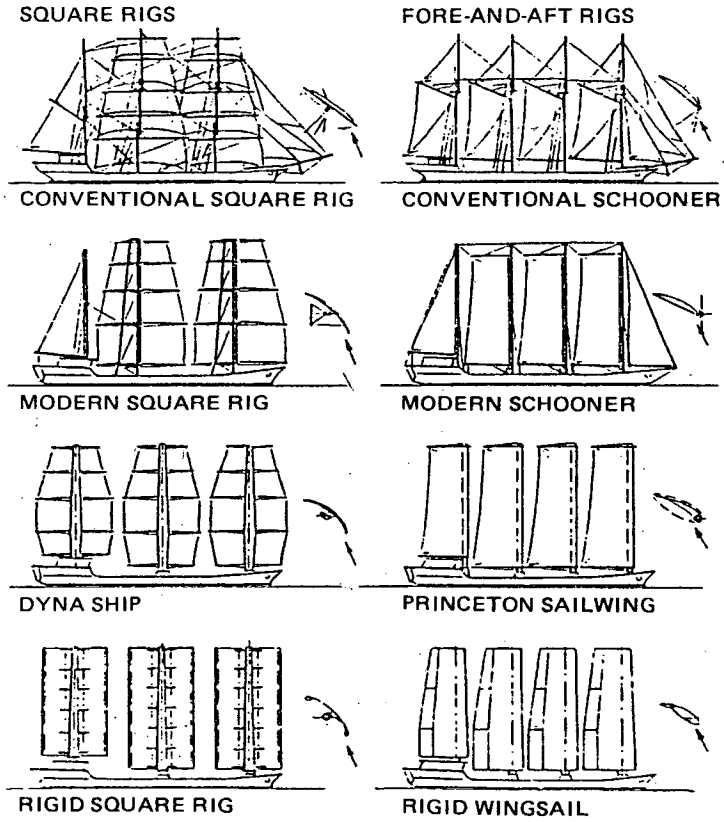
(iii) Self-supporting, rotatable mast; and

(iv) Adoption of rigid airfoil wings (with flaps).

The superiority of the rigid airfoil wingsail over a well-shaped soft sail is restricted to the extremely close hauled range. Such a rig is especially suitable for light weight, high speed craft, or as wind assistance when the engine propulsion is providing a relatively high ship speed with respect to most wind conditions. Moreover, reefing of large rigid wings is impossible or extremely difficult and the integration of loading gear into such a rig

Figure 3

Possible Development Lines of Traditional Sailing Rigs



may cause serious problems. Self-supporting masts tend to have high structural weight and costs and subdivision of the sail area of modern square rigs seems worthwhile only for very large units.

So called advanced wind propulsion systems, such as Flettner rotors, horizontal or vertical axis wind turbines, or kites, show some interesting performance characteristics, especially in view of applications to wind-assistance, but a comparative evaluation requires further research efforts. After thorough preliminary considerations, further investigations for the selection of suitable rigs for interisland cargo ships were focused on the comparative evaluation of modern multimasted fore and aft (schooner) rigs. Although some of the components and detailed solutions for this rig type can be adopted from modern sailing yacht technology, there are distinctly different requirements due to the absolute dimensions, the long term operation of the vessel under commercial conditions, and the additional function of loading and unloading cargo.

In principle, the fore and aft sails of a schooner rig can be fixed as staysails on diagonal stays, as Bermuda sails, or as gaff sails behind the masts (see Figure 4). On a multimasted cargo ship with the hatches between the masts, the diagonal staysails would impair the cargo handling operations, thus being only suitable as foresails. Triangular Bermuda sails utilize only a part of the rectangular space between the masts and therefore need higher masts and longitudinal overlap.

Almost rectangular gaff sails have the best fit into the available space and are expected to offer the best relative adjustability for optimum aerodynamic interaction in a multimast arrangement. Alternative configurations of gaff sails differ especially with respect to the gaff and roller reefing system. A conventional oblique gaff allows only vertical reefing on a boom roller, which is incompatible with the function as a loading derrick. Horizontal reefing on a vertical roller behind the mast is possible with a (double) wishbone gaff or with a fixed horizontal gaff.

The INDOSAIL concept for sail shape control aims at simple appropriate technology for long-term commercial use, the requirements of which differ significantly from those of modern racing sails. Commercial sails should be neither dependent on expensive, extra strong, sheer-stiff but short life material, nor on extra skill of the maker and the crew.

Consequently, the INDOSAIL concept of a 'suspension sail' (see Figure 5) is that of a soft cloth, flat cut sail, with single horizontal cloth tension and suspended by curved leech and luff ropes. Each horizontal width of cloth may be imagined as hanging independently from the neighboring cloth between the curved leech and luff ropes similar to a vertically standing suspension bridge. Each width of cloth attains its sail profile shape and camber in the equilibrium of: aerodynamic pressure difference, horizontal

Figure 4

Indosail Rig Model Series for Wind Tunnel Tests

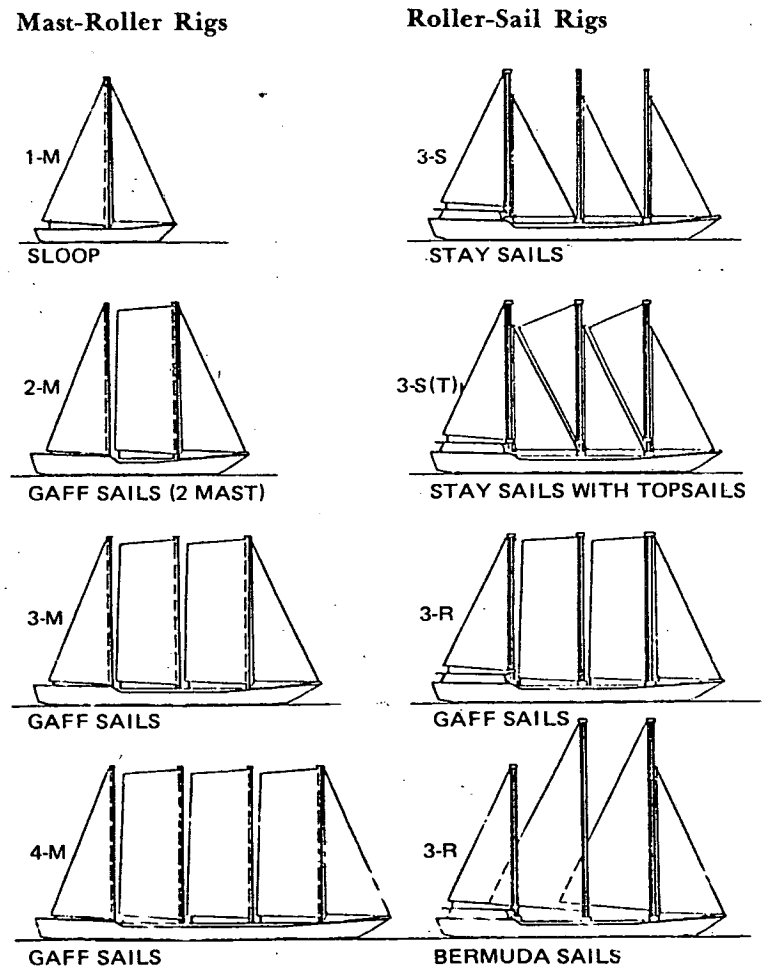
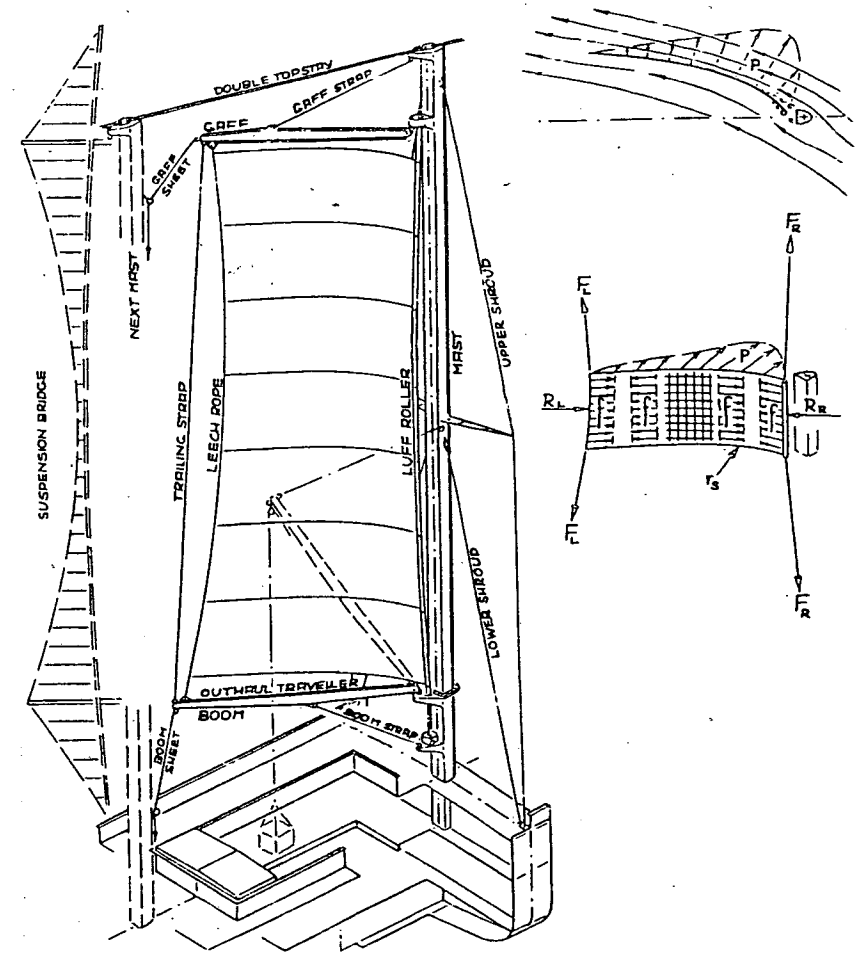


Figure 5

Concept of the Suspension Sail



LOCAL AERODYNAMIC PRESSURE DIFFERENCE	P
LOCAL RADIUS OF SAIL PROFILE	r_s
HORIZONTAL SAIL-CLOTH TENSION	$f = r_s P$
RADIUS OF LEECH ROPE CURVE	R_L
LEECH ROPE TENSION FORCE	$F_L = R_L f$
LUFF ROLLER TENSION FORCE	$F_R = R_R f$

cloth camber, horizontal cloth tension, vertical leech (luff) rope curve and rope tension forces.

A triangular (Bermudan) or quadrangular (gaff, sprit or square) suspension sail should have a loose foot (and top), and in the case of roller reefing on a luff roller, the leech rope moves horizontally by traveller(s) on the boom (and gaff). The high vertical control forces are not introduced directly into the sail cloth but into strong leech and luff ropes and transformed by the suspension mechanism into the much smaller horizontal cloth tension required to maintain the desired camber of the sail. Only small, localized vertical cloth tension is to be expected from secondary effects such as gravity and the adjustment of cloth relative to the leech and luff ropes.

No extra sheer or bias stiffness of the sail cloth is required for a suspension sail due to single axial warp (or weft) stresses. On the contrary, a certain sheer stretch is desirable for an easy mutual compensation between the curvatures of the leech and luff rope without wrinkles in the sail cloth. This is especially required if only the leech of the sail is hollowcut with a camber in the order of three to five per cent, while the straight cut luff is fixed to a pretensioned roller, the latter sagging significantly only at higher wind loadings.

AERODYNAMIC EVALUATION OF ALTERNATIVE RIGS

The selection of an appropriate rig type for the INDOSAIL vessel was supported by an extensive test program in a wind tunnel. To be able to examine the aerodynamic characteristics of different sail and mast configurations, we carried out about 70 test series in the wind tunnel of Institut fuer Schiffbau (IFS) of Hamburg University. The sail models with about 15 cm chord length were made of sheet metal with a given profile shape of about 10 per cent camber. Rigid models were chosen in order to achieve a Reynolds number of 4.10^5 at a flow velocity of 40 meters per second. Soft sail models of so small dimensions would have been difficult to manufacture with the required accuracy and realistic and reproducible trimming would have been practically impossible under the high wind pressure of 1000 N/sq m.

The investigated sail types were almost rectangular gaff sails, triangular Bermudan and staysails, in different variations and adjustments. The main variation was the shaping of the leading edge at the mast, from the ideal form of the rotatable mast as an integrated reefing roller ('mast roller') via the structurally simpler reefing roller behind the mast (roller sail) to the freely tensioned roller between the legs of an 'A-frame' mast. For comparison, special devices were also investigated such as different rigid symmetrical airfoil wings and a Princeton sailwing.

Completed rig models were tested in about 80 test series at a Reynolds number of 3.10^5 in order to investigate the inference effect on various multimasted schooner rigs. In a first test series with one to four masted models with idealized 'mast roller' (gaff) sails, the effect of the number of masts was studied. The influence of the details of sail and mast type was investigated in a second series of three masted models with 'roller sail' rigs as Bermuda and staysail schooner and as gaff sail schooner with middle and 'A-frame' masts. Figure 6 shows, as an important part of the results, the coefficient of the maximum achievable driving force component, depending on the angle of inflow of the apparent wind relative to the ship's head.

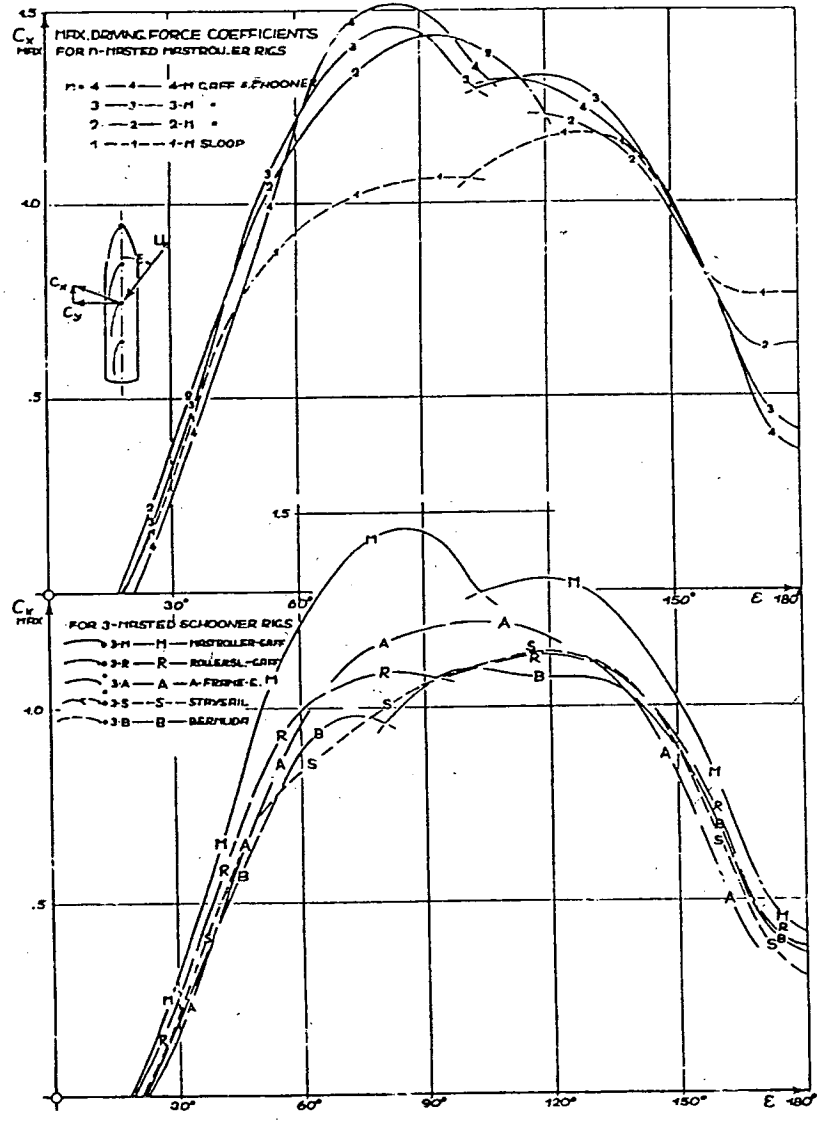
By increasing the number of masts from two to four, the best close hauled angle of apparent inflow increases by not more than two degrees per additional mast, due to the decreasing effective aspect ratio of the total rig. At the maximum achievable driving force between 70 and 90 degrees inflow, the tendency is even reversed, which means that the maximum driving force increases more than the sail area with increasing number of masts. In the reaching condition, the driving force coefficients are practically independent of the mast number. The greater mutual sheltering effect with higher mast numbers when running downward is not important in practice, since in this range tacking to leeward is the better strategy.

These suprisingly favorable performance properties of multimasted rigs are due to the total sail area being subdivided into a system of leading edge 'slats' (foresails or jibs), main wing (mainsail), and one or more slotted trailing edge flaps (following sails), in much the same way as a modern aircraft wing during approach to landing. Here, also, the angles of the single wing or rig elements are carefully adjusted according to the local flow conditions in order to shift the flow separation in the whole system in the range of high lift coefficients.

A comparison of the different alternative sail and mast types in the form of three masted rigs in the total range of inflow angles indicates a clear superiority of the aerodynamically cleanest 'mast roller' gaff rig (M) (see Figure 6). This may be regarded as an aerodynamically ideal case but structurally complicated and expensive. Next best variants are the 'roller sail' gaff rigs with middle masts (R) and with 'A-frames' (A). In the close hauled condition the middle masts are superior due to their lower drag, while in beam inflow the lower perturbation of the A-frame on the leading edge of the sails yields better results. Presumably both rigs might be improved by using profile masts, but a slight superiority of the middle mast on the important close hauled course is still to be expected. The staysail (S) and Bermudan rigs (B) follow closely but both of them are less suitable for a cargo ship due to operational disadvantages.

Figure 6

Maximum Driving Force Coefficients of Alternative Schooner Rigs



On the basis of the wind force coefficients, as determined by the wind tunnel tests and corresponding data for the hull derived from oblique towing tests, the achievable ship speed under sail is calculated by establishing the equilibrium of forces on the rig and on the hull, for a range of wind speeds and for all courses relative to the wind.

These speed predictions together with statistical data on the wind conditions in the served sea area, allow the estimation of possible average (service) speeds of a sailing ship design. As an example, Figure 7 shows the likely average speed (V) of the 1,500 deadweight ton (dwt) 65/4 INDOSAIL design in relation expected average windspeed (U) under the assumption that all courses relative to the true wind are equally frequent. Three lines show the expected average speed under sail on direct courses, the effect of routing deviation, and the effect of an auxiliary drive providing a minimum speed of four knots for 35 per cent of the time. For comparison, an equally calculated prediction for the square rigged sail training ship *Gorch Fock* is also plotted. Although this latter vessel has an equal displacement, a greater ship length and a larger sail area, the modern design of the INDOSAIL vessel is expected to be, on average, nearly 20 per cent faster than the conventional square rigger under equal conditions.

DESIGN OF THE PROTOTYPE SHIP

The principal characteristics of the INDOSAIL prototype vessel are as follows:

(i) Auxiliary sailing vessel ('motor-assisted windship');

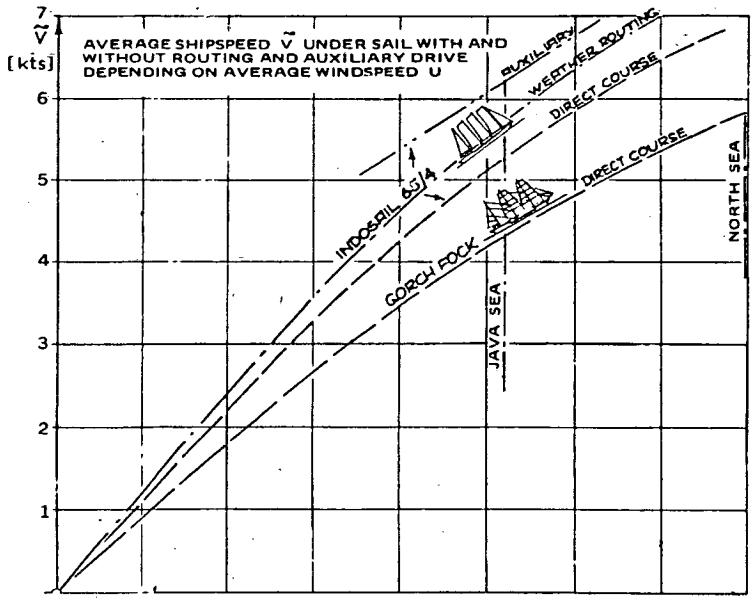
(ii) Schooners with three or more masts with jib, gaff sails on the forward masts; and

(iii) Bermudan sail on the mizzen mast (trapezoidal sail plan).

As a guideline for component dimensions, a basic module was defined consisting of one cargo hold, one hatch, one mast with one gaff sail and cargo handling boom. The key dimension is the mast spacing which not only determines the area of a single sail unit, but also the appropriate beam of the ship, the hold capacity and the hatch size. Going not too far beyond the dimensions of the rigs of already built cargo schooners, the mast spacing (S) of a novel prototype rig should be not more than about 15 meters resulting in a single gaff sail area of about 350 sq m. By way of comparison, the largest commercial sails of the past were about 300 sq m in area.

Figure 7

Speed Prediction for Standard Wind Statistics



With appropriate dimensions of beam (B) = 0.8S = 12 meters, draft (T) = 0.35S = 4.5 meters and a midship section with deadrise and C_M 0.87, the displacement of a midship module may be about 725 tons at a structural weight of not more than about 150 tons. Similar preliminary design estimations for the fore and afterbody sections yield approximate main dimensions for a modular series of three, four and five masted ships of this modular concept (Figure 8).

With a mast spacing (S) = 15 meters, the hatch length is limited to about 10-11 meters due to the space required for mast, winches, hatch coamings, etc. This is sufficient for almost all usual general cargo units except for occasional empty 40-foot ISO containers. However, two such containers can easily be stored on deck on the sides of each hatch since the shrouds of the masts are only in the transverse plane without any longitudinal spread, leaving 15 x 12 meters of deck and hatch area free and undisturbed access for cargo operation.

A greater mast spacing would result not only in greater rig and sail dimensions but also in a greater beam and draft of the ship, rendering the vessel unsuitable for many shallow water ports. If in a later stage of development a hatch length of 12.5 meters will be required for 40-foot containers, then the resulting minimum mast spacing would be 18 meters with the consequences of a single sail area of at least 500 sq m, a beam and draft of 14.5 and 5.5 meters, respectively, and a minimum deadweight of the three masted version of 1,500 tons. Even more problematic than the 20 per cent greater dimension and the 70 per cent greater weight of the structural components, seems to be the 40 per cent greater area of the individual sails.

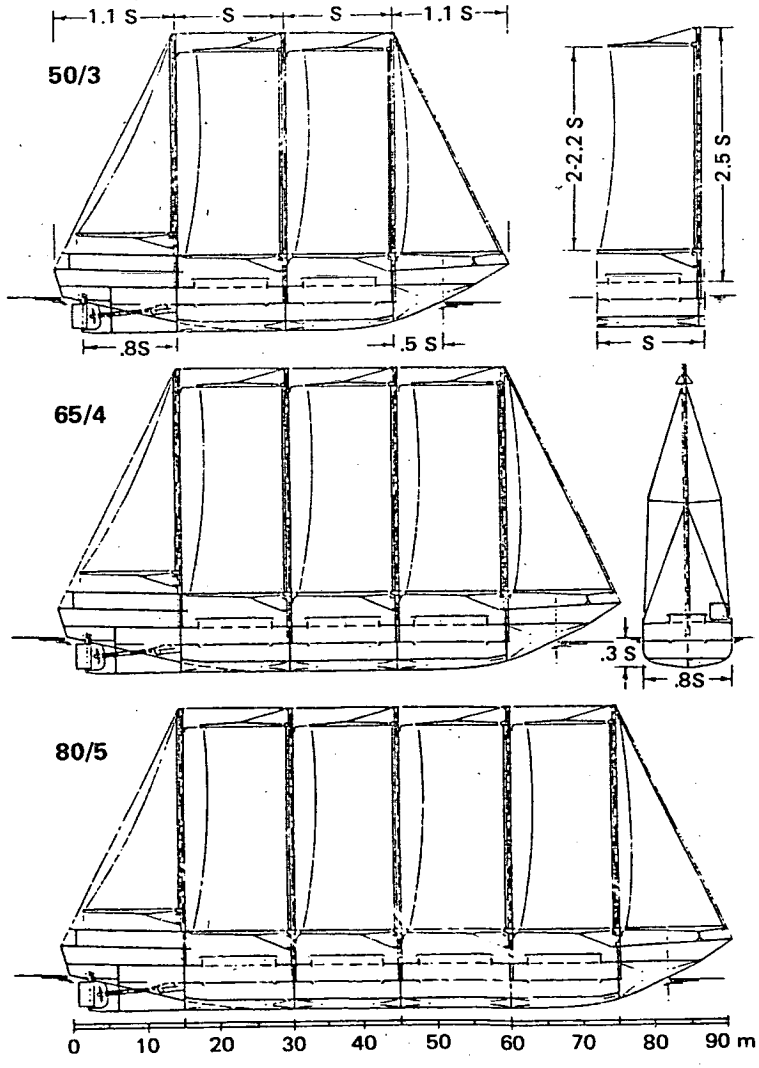
The few applications in the past of such large area sails are limited to short-term use as light weather sails on big yachts. No practical experience is available for long-term commercial operations on heavy cargo ships in every weather. Thus, further investigations are required regarding the practical feasibility of extremely large sails, involving rig weight and sail handling to a lesser degree, but primarily addressing problems of controlling the shape of the sail, strength of the sail fabric, seams and leeches, and forces in the rig elements, such as masts, spars, straps, etc.

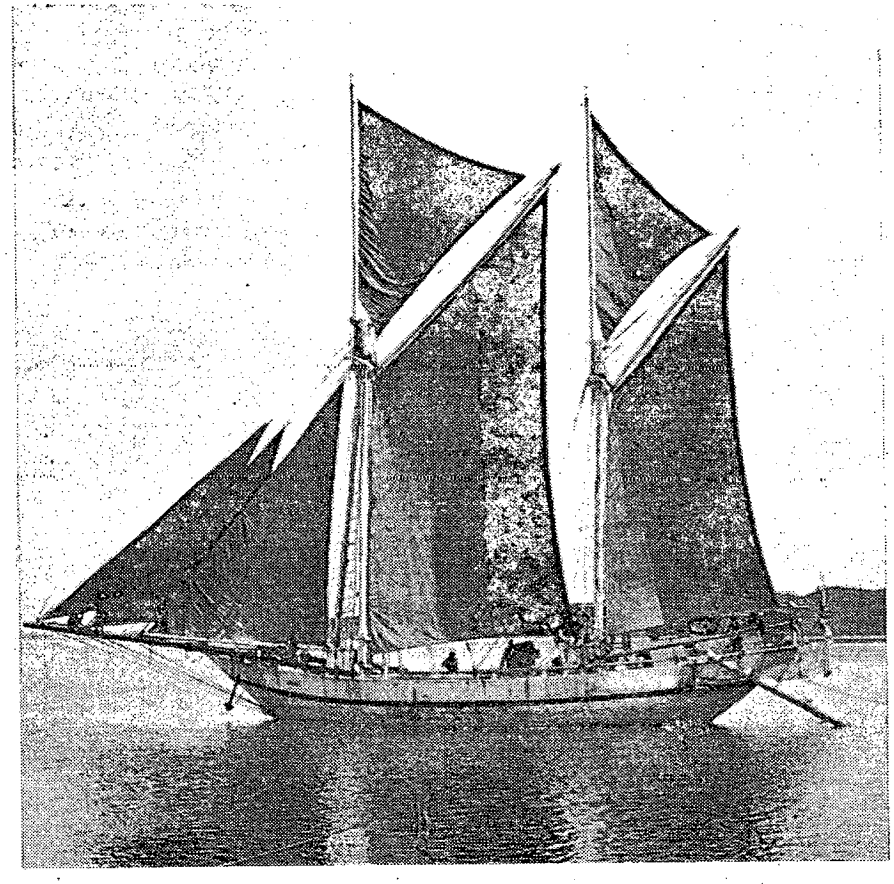
For the foregoing reasons it was decided to design and build the prototype ship on the basis of the 15 meter modular length and to envisage the later development of an optimal parallel (Mark II) series of greater number of units for the major ports and routes, on the basis of practical experience with the Mark I series.

The modular concept implies that vessels of different sizes, but of the same series, have the same breadth, draft, depth and mast height. It is, therefore, essential for the practicability of the concept that the short and the long versions meet the same stability criteria, as established by the

Figure 8

Modular Series





Pinisi, traditional sailing vessel of South Sulawesi.

German (GL) and Indonesian (BKI) ship classification authorities. Furthermore, a maximum heeling angle of ten degrees should not be exceeded under full sail with a full load of homogeneous cargo up to a wind speed of nine meters per second (17.5 knots), which applies in the Java sea during 90 per cent of the year.

Figure 9 shows that with a breadth of 12.0 meters, sufficient stability conditions have been obtained for all three modular vessels. Metacentric height, righting arm, range of stability and heeling angle are not very much different for all the vessels, due to an optimum tuning of rig size to displacement and breadth/draft ratio.

To minimize cost and risk, it was decided to build the prototype vessel in the shortest 50-meter version (INDOSAIL 50/3) under the parallel classification of BKI and GL + A 4 'Motorsailer', with a freeboard of 2.0 meters. Besides the Indonesian national safety rules, the requirements of the 1974 Safety of Life at Sea Convention (SOLAS) and the International Convention and Protocol for the Prevention of Pollution from Ships (MARPOL) 1973/78 were applied.

As later lengthening (of the same vessel) to 65 meters and 80 meters is intended, the layout of the scantlings is not the minimum for the 50 meter-vessel, but enables lengthening up to 80 meters without further reinforcements. The excess steel weight over the minimum is only 16 tons or 2.5 per cent of light ship weight due to an increase in plate thickness of 1.5 and 1.0 millimeters in deck and bottom plating.

After preliminary tank tests with three different versions, the model of the final lines of the Prototype INDOSAIL 50/3 (Figure 10) was extensively tested in sailing conditions and under engine.

The General Arrangement (Figure 11) shows the twin hatch, three masted Prototype INDOSAIL 50/3, with raised poopdeck and forecastle, engine and accommodation aft, with continuous tween deck and double bottom. There are two wheel stands in the wheelhouse which is on the poopdeck, to permit good visibility when under sail. An additional experimental wheel stand on the deckhouse will be tested to improve visibility while maneuvering under engine during port exit and entry. Accommodation is provided for 30 persons, in accordance with special local demand.

Alternative configurations of the power and propulsion plant have been thoroughly investigated, to find an appropriate solution for the wide range of operational conditions. The power required for propulsion is zero during pure sailing; about 20 to 50 kW as motor assistance during light winds; about 60 kW for speed of six knots under deadcalm conditions, or during port entry and exit; and up to 100 kW to ensure maneuverability against heavy weather. The electrical generator requirements are in the same order; about

Figure 9

Comparison of Stability Heeling Angle (φ)

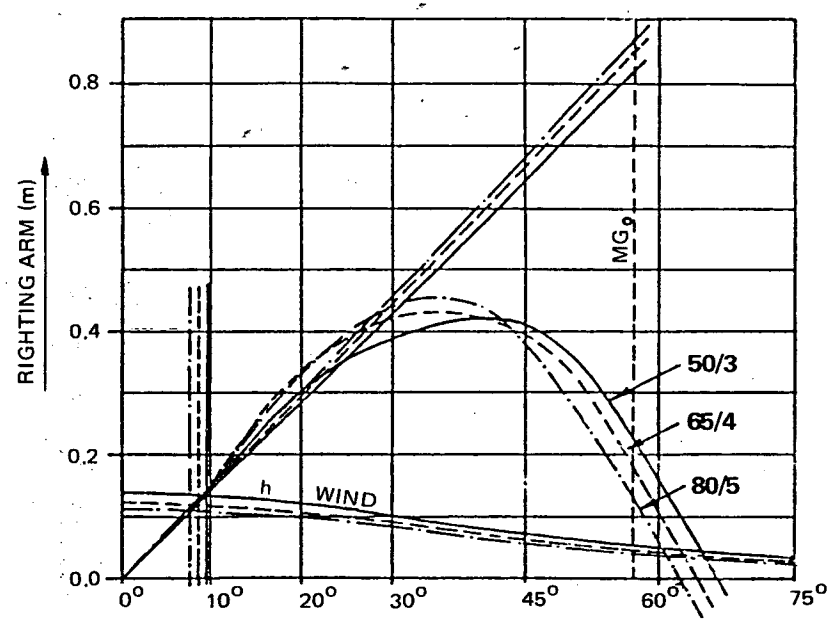


Figure 10

Lines Plan for Prototype Vessel 50/3

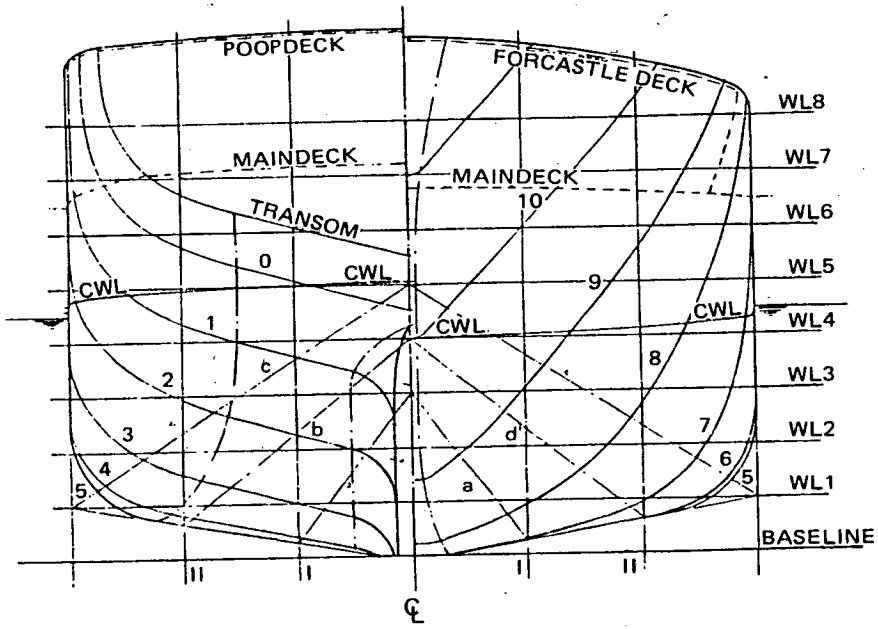
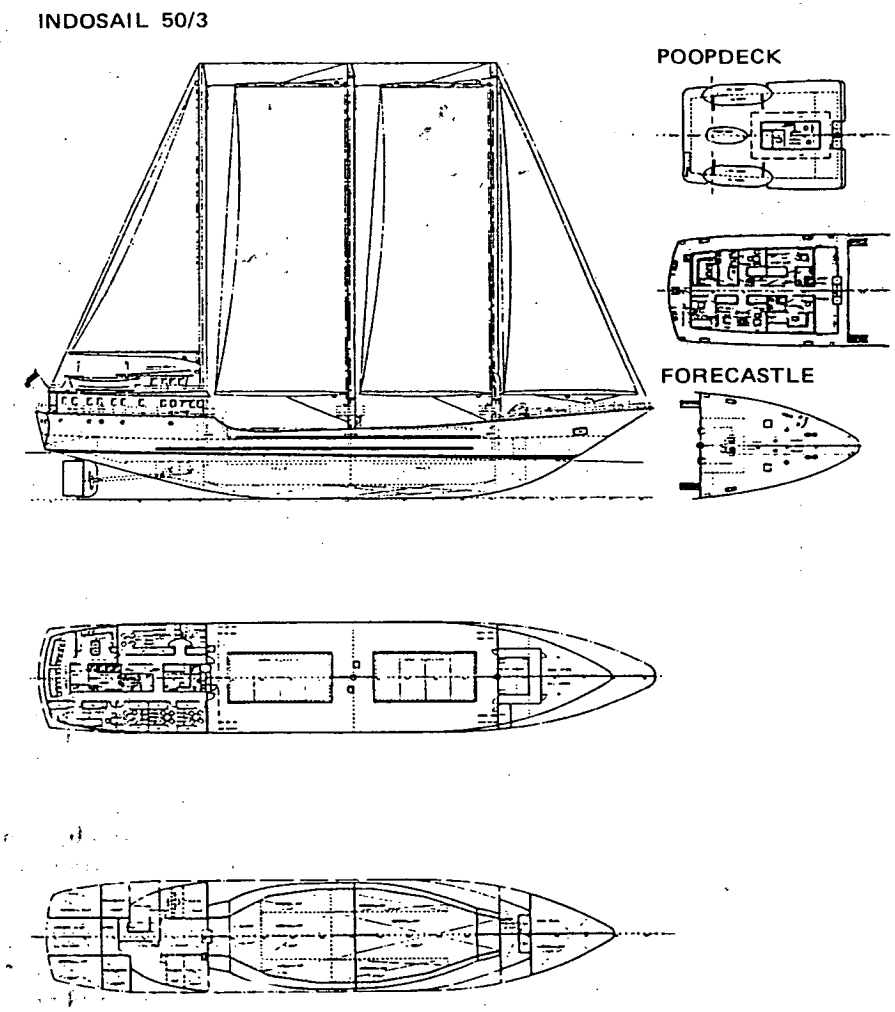


Figure 11

General Arrangement



40 to 80 kW at sea, about 25 to 70 kW in port; and up to 100 kW during cargo operations.

The solution found for the prototype vessel is a simple diesel-electric power plant (Figure 12) of two 130 kW diesel engines, each coupled to a three phase-alternator for electrical energy and a direct current (DC) generator for propulsion power. The DC propulsion motor is supplied with DC-voltage which is continuously controlled by adjusting the excitation of a DC control generator ('Leonard-System'). The layout of the DC propulsion motor is for 70 kW continuous output and 100 kW for one hour.

Depending on the power demand for propulsion, automatic circuit breakers cut non-essential consumption in two steps, to avoid overloading of the diesel engine. If the propulsion demand exceeds 75 per cent of the capacity of one engine, propulsion and electrical energy will be supplied by separate generators, respectively.

A sailing rig is a propulsion plant with low energy density, especially under light wind conditions. The rig has to pay back its installed and operating costs in competition with the installed and operating costs of a motor propulsion plant.

The rig for the INDOSAIL prototype coastal cargo vessel is being designed according to the following criteria:

(i) Efficiency as a main propulsion system;

(ii) Economy in construction and service;

(iii) Safety for crew and ship;

(iv) Simplicity in construction, handling and maintenance;

(v) Resistivity against sea water and weather impact; and

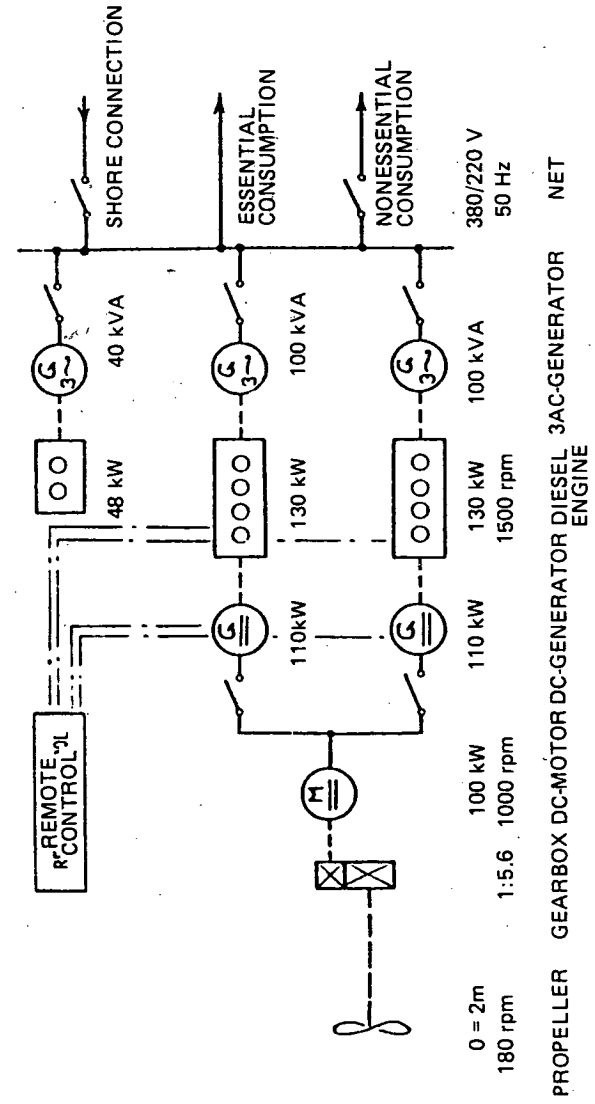
(vi) Computability based on reasonable load assumptions and theoretical models.

To meet these criteria, the rig design had to be modified step by step in the course of two years of experience, to a greater simplicity in construction, handling and maintenance.

According to the modular concept, the main rig module (Figure 5) consists of mast, gaff, sail boom, upper and lower shrouds, double top stays and one quadrangular gaff sail. Gaff and boom are held in the vertical position by a fixed gaff strap (topping lift) and a boom strap (kicking strap), the tips being connected behind the trailing edge of the sail by a trailing strap, closing the quadrangular frame of mast, gaff and boom. The sail is set in this frame between the luff roller behind the mast and the leech

Figure 12

Diesel Electric Power Plant



rope in a curved leech seam of the flatcut sail ('suspension sail' system). The gaff and boom are controlled by sheets. Together with a cargo derrick on the next mast the sail boom can be used for cargo handling in union purchase. Alternatively, the necessary change of rigging from sailing to cargo operation can be avoided by providing two separate cargo derricks on the next mast.

The foremast module carries, in addition, the forestay and the jib sail which is set in a balanced triangular frame with luff roller, pendulum boom and trailing strap. This enables an easy control of sail shape even on broad reaching courses. The mizzen module carries only the triangular Bermudan mizzen sail under the double aft stay.

All spars are of steel, the masts being of semielliptical cross section which was found in wind tunnel tests to reduce the disturbance of the leading edge flow on the sail. The sails can be reefed and stored on the luff rollers behind the masts.

Commercial sail cloth has to resist sun radiation for more than 10,000 hours of exposure. Thus, polyester (Dacron, Terylene) material as used for racing of yachts and training vessels would have to be three to four times heavier than strength requirements.

From available textile fiber materials today, polyacryl-nitril (Dralon, Orlon) appears to be of exceptional resistivity to ultra violet radiation and weather impact. Available cloth, well established for sunshades and awnings, woven of staple fiber yarn has been tried on a 20-meter experimental vessel and showed satisfying performance under the suspension sail system. However, endless fiber yarn and increased density of the weave could improve its suitability as sail cloth and especially reduce long-term permanent stretch.

The design of traditional sailing rigs has been based on experience supported by simple theoretical calculations. The design of the novel rig type has to be based almost exclusively on theoretical calculations supported in our case, as required by the ship classification societies, by a cross-check of the calculations and load assumptions against tests on a 20-meter experimental vessel carrying a two-masted 50 per cent full-scale test rig.

Due to high bending moments, compression forces and the inevitable flexibility of the rig, static calculations must account for deformations in all elements of the rig, including the sail cloth. The load assumptions are derived from wind pressure, stability criteria and wave induced motion.

Criteria for the strength of the rig have been set up as follows:

(i) The rig has to survive all heeling conditions from zero to 90 degrees;

(ii) The maximum survival load is based on the maximum sum of external heeling moment and the gravity load due to heeling, or, on the maximum sum of roll acceleration and the gravity load due to heeling;

(iii) The maximum service load condition is a close hauled course with ten degrees heeling angle; and

(iv) Assumed rolling and pitching accelerations shall, in accordance with the ship classification society rules, be verified by full-scale tests on the 20-meter test vessel.

The rig, with minimum scantlings for bending and buckling strength, is very flexible, especially in the distance between the tips of gaff and boom. Under maximum (full sail) service load, the frame consisting of mast, gaff and boom would deform and the leech rope would sag so much that the sail camber increases from 12 per cent to more than 30 per cent, which would considerably impair the aerodynamic performance.

An efficient solution is prestraining, not the leech rope, but a stiff trailing strap between the tips of gaff and boom, to the maximum service load of the leech (see Figure 5). Below the maximum service load, the stiffness of the rig is governed by the tension stiffness of the trailing strap and the sail shape is virtually stable, while the leech rope gradually takes over the load from the trailing strap with increasing wind pressure on the sail.

Above the maximum service load, the rig's behavior is as flexible as without prestrain. Thus, the loading of the rig increases much more slowly than the wind pressure. Slack in the trailing strap between the tips of boom and gaff is a clear signal for the need to reef. The same applies, in principle, to the prestrained trailing strap of the triangular sails between boom tip and mast top. All rig functions, sheeting as well as setting and reefing the sails, is designed to run by electric winches, controlled from each mast foot, with the possibility to operate the sheeting from the wheelhouse. By increasing experience with the prototype ship, remote control and automation will be introduced step by step up to an appropriate level using safety and economy criteria.

ECONOMIC ASSESSMENT

Economic assessment is made in keeping with the phased execution of the project. At this present research and design phase, the economic criteria that should be considered are identified. These criteria cover both costs and potential earnings in the future commercial operation of the proposed ships.

The second stage of economic assessment will be made at the stage of the sailing trials. Observations made during the sailing trials, especially regarding sailing speed, the consumption of fuel and the speed of loading and unloading, are some of the factors to be studied in the economic assessment. Observations obtained from the sailing trials will be used as input in planning the final design.

During the first phase, data for assessing the economic feasibility are collected. The data consist of three targets, namely:

(i) Comparatively cheap construction costs;

(ii) Comparatively cheap operational costs; and

(iii) Reasonable prospects for adequate operational income.

More specific assessments will take into account the factors that have an influence upon the level of economic and financial feasibility, namely:

1. Aspects of Cost

(a) Cost of construction (including interest):

(i) Construction of rigging;

(ii) Construction of hull;

(iii) Cargo handling equipment; and

(iv) Engines.

Efforts will be made to ensure that, as far as possible, the price of the vessel will not be higher than that of regular liners of similar size being built in Indonesia at present. The chief targets for keeping down the costs of construction are:

(i) The most economical possible costs of rig construction; and

(ii) The cost of interest during construction. This will involve assessment of sources of investment funds both domestic and foreign.

(b) Operational Costs:

(i) Fuel;

(ii) Port fees;

(iii) Crew;

(iv) Insurance;

(v) Repairs, maintenance and supplies; and

(vi) Management, claims and agency.

As well as optimizing the costs of construction, operational costs must be minimized. This is important, since the experience of regular liners in Indonesia shows that operational costs form 60 per cent of total costs. In assessing the operational costs, we will concentrate mainly on the following components:

(i) Cost of Fuel
One of the most important economic benefits for the use of the 'motor-assisted sailing vessel' is the fuel saving. On the whole, experience shows that the costs of fuel constitutes 36 per cent of the direct operational costs of regular liner service vessels.

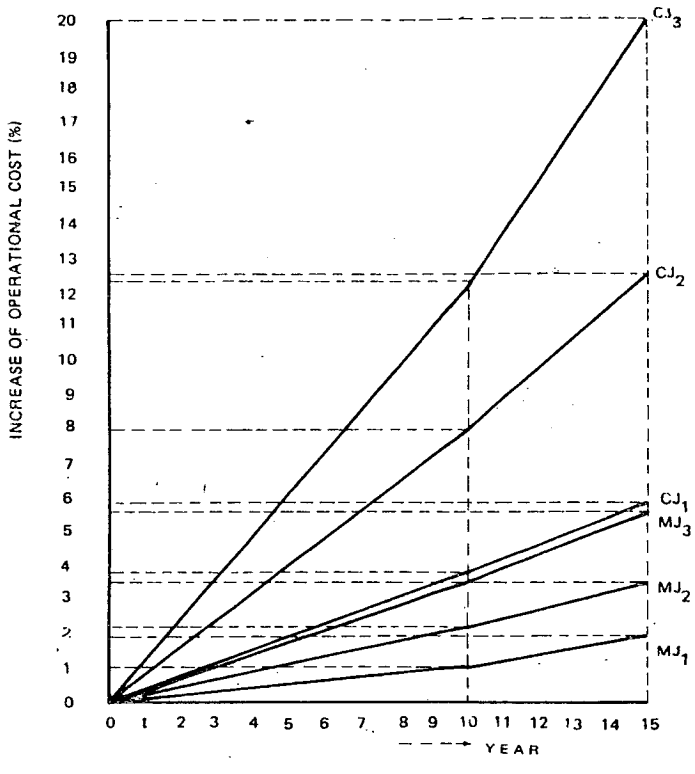
(ii) Cost of Crew
For regular line ships of 3,000 dwt, this cost amounts to 15 per cent. For vessels of 1,000 dwt, crew costs are about 21 per cent of operational costs. Reduction of one crew member can mean reducing operational cost by one per cent, all other things being equal.

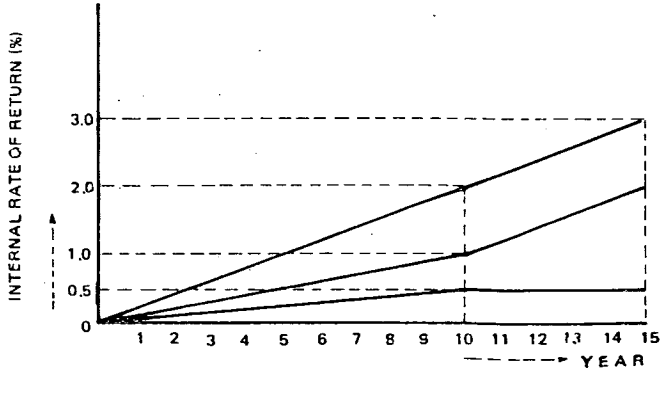
(iii) Cost of Repairs, Maintenance and Supplies
The cost of repairs, maintenance and supplies for the rig system of sailing vessels is of additional importance than for motor vessels. In the section on Design of the Prototype Ship, six criteria are given for design of the rig system. Two of them, namely: economy in construction and service; and simplicity in construction, handling and maintenance, are related to economies in the cost of repairs, maintenance and supplies.

Other cost components, such as port costs, management and so forth, are, in spite of their importance, more greatly influenced by local conditions in operation of the vessels.

Figure 13

Influence of Increased Oil Price





2. Prospects of Income

(a) Determinants of Income

The main factors that determine the level of income from the operation of ships are:

(i) Average sailing speed;

(ii) Loading/unloading capacity;

(iii) Stowage factor;

(iv) Distances covered;

(v) Productivity of ports;

(vi) Load factor; and

(vii) Tariffs.

With this in mind, targets for assessment cover the first three factors above as follows:

(i) Average Sailing Speed

This target is broken down further in order to obtain a configuration of the most economic average sailing speed taking into account wind conditions and fuel costs as well as the number of trips and the income that can be produced.

(ii) Loading/Unloading Capacity

This factor should receive attention, because it will, together with the speed of sailing, determine the number of trips and the volume of cargoes, and therefore has significance for the income from operation of the vessel.

(iii) Stowage Factor

Since the prospects of income are determined by manifest ton, stowage is also an important factor to be taken into account. The composition of cargoes is obtained from experience with the average general cargo carried.

(b) The System of Financing the Operation of Ships

Another matter for specific consideration is the system of ship leasing in Indonesia. In particular, for vessels of the regular lines, PT. PANN (Company for Development of the National Commercial Fleet) acts as leasing agent. The leasing system has been of

great assistance to shipping companies, especially small companies. More than 30 per cent of the companies operating the regular liner services in Indonesia are customers of PT. PANN, for all or for some of their ships.

(c) Some Provisional Figures
Various studies of energy indicate that the price for fuel oils will continue to rise in the long term, although they tend to be constant at present, and have even fallen slightly. It is estimated that the real price for fuel oils will rise by an average of three per cent a year (BPPT and Bechtel Intern Inc., 1980).

Based on 1985 prices for fuel oils and alternative price increases of one, two and three per cent, Table 1 and Figure 13 show the influence these increases will have on total operational costs for vessels of types *Caraka Jaya*, of 1,000 dwt and the 950 dwt *Maruta Jaya*[1], with the assumption that other components of operational costs remain constant.

Table 1
Influence of Increased Price for Fuel Oil on Total Operational Cost

Price Increase for Fuel Oil	Increased Operational Cost (%)	
	Caraka Jaya	*Maruta Jaya*
1. Increase of 1% a year		
—10 years	3.8	1.0
—15 years	5.8	1.9
2. Increase of 2% a year		
—10 years	8.0	2.2
—15 years	12.5	3.5
3. Increase of 3% a year		
—10 years	12.4	3.5
—15 years	20.1	5.6

If we take the case of the 1,000 dwt *Caraka Jaya*, where operational costs are about 60 per cent of the annual earnings, the savings that can

1 *Caraka Jaya* is a 1,000 dwt motor coaster and *Maruta Jaya* is a proposed INDOSAIL sailing vessel.

be made by a sailing vessel in comparison with vessels driven by fuel oil alone, and the influence upon the internal rate of return, is as shown in Table 2.

Table 2
Comparison of Savings in Operational Cost of Motor Ships and Influence of Such Savings Upon the Internal Rate of Return

Price Increase for Fuel Oil	Savings in Operational Cost	Influence on Internal Rate of Return
	(%)	(%)
1. Increase of 1% a year		
—10 years	2.8	0.5
—15 years	3.9	0.5
2. Increase of 2% a year		
—10 years	5.8	1.1
—15 years	9.0	2.0
3. Increase of 3% a year		
—10 years	8.9	2.0
—15 years	14.5	3.0

Note: Calculation of the Internal Rate of Return is based upon a 20-year period for operation of the vessel.

STATUS OF THE PROJECT AND OUTLOOK

Trial of the 1:5 Scale Model Rig System

Before the 950 dwt sailing ship *Maruta Jaya* was built, a trial was made on the rig system on a scale of 1:5. The rig was installed on a ferrocement platform built like a sailing ship.

The ferrocement 'ship' on which the model rig system was installed had an overall length of 27.40 meters, a length between perpendiculars of 18.00 meters, a moulded beam of 6.25 meters, a height of 3.01 meters, draft of 2.50 meters, and block coefficient of 0.42. The sails installed on this model

rig system had an area of 240 sq m, besides which the vessel was equipped with a supplementary engine of 47 horsepower and a two bladed propeller.

For the time being, the trials of the model rig system for the *Maruta Jaya* are being held in the Bay of Jakarta and the waters of the Pulau Seribu archipelago. In the next stage, wider ranging sea trials will be held.

The results of these trials of the model rig system are very badly needed as input data for designing the construction of the *Maruta Jaya*. The input data expected from these trials concern the strength of the rig system itself under the influence of actual wind power. Additional benefits of these trials will result from operational experience gained by the crew and the research team, who will thus become acquainted with the method of operating input which will reduce any deviations from planning.

The trials that have been made were monitored by researchers from BPPT, the Laboratory for Strength and Materials, Components and Structures (United Kingdom) and experts from the Federal Republic of Germany. A computer, oscilloscope and various measuring equipment were used in obtaining the experimental data.

Building the *Maruta Jaya*

Classification society drawings, production and other detailed drawings for the building of the *Maruta Jaya* sailing ship have been completed at the PT. PAL Indonesia Shipyards, Surabaya. This shipyard was appointed by the Government to build the ship because it has experience in the maintenance and repair of a training sailing ship. In addition, PT. PAL Indonesia will later be the center for the development of shipping technology in Indonesia.

An expert from the Federal Republic of Germany (as technical assistant) and several members of the BPPT Research Team will also be involved in building the *Maruta Jaya*.

Preparatory work prior to actual construction of the ship commenced in early November 1985. Following keel laying in early February 1986, completion is expected towards the end of January 1987.

After the sailing vessel has been operating on a trial basis for two years, the ship will be lengthened by the modular system, so that the length (between perpendiculars) will be 65 meters and it will have a capacity of 1,550 dwt. Two years later, it will be further lengthened by the same system, to reach a length (between perpendiculars) of 80 meters and with a capacity of 2,050 dwt. Once it can be proved that the *Maruta Jaya* and her sailing rig is suitable for Indonesian waters, the possibilities of applying the rig to commercial vessels, or other special ships, will be studied.

Trials of the *Maruta Jaya*

It is planned that sailing trials of the *Maruta Jaya* will cover two principal aspects, namely:

(i) technical trials; and

(ii) financial and economic trials.

Technical trials will be made to obtain the following data on:

(i) maneuverability, both in port and at sea;

(ii) the ship's sailing speed over a wide range of wind and other meteorological conditions, using a combination of engines and sails, as well as engines only or sails only; and

(iii) the strength of the rig system.

Financial and economic data obtained during the trials will mainly be as follows:

(i) average sailing speed;

(ii) loading/unloading capacity;

(iii) productivity of ports;

(iv) load factor; and

(v) fuel costs.

For comparison purposes, technical, economic and financial data will also be analyzed for conventional motor vessels of the same size and on the same routes.

The ship's crew and captain will be recruited from among personnel with experience in the operation of sailing ships. The BPPT research team will work together with one of Indonesia's shipping companies for the execution of the operational plans.

QUESTIONS AND ANSWERS

Q: How was the cargo boom problem solved? Were lifting blocks installed? (Mr. R. G. MacAlister)

A: Using the mainsail boom for cargo handling would be too laborious on the INDOSAIL vessel due to re-rigging requirements, thus a second boom is planned to be fitted to the mast.

Q: Could you describe the sheeting requirements? How is the sail rigged in high wind conditions? (Admiral M. H. Khan)

A: The sheeting is simple in principle. There is one sheet for the gaff and one for the boom. Vertical control is via the kicking strap. The frame of mast, sail and gaff is geometrically stable up to maximum load conditions.

Q: Is the boom height raised because of visibility problems? (Capt. R. Maharaj)

A: Visibility is improved by the relatively high boom but it is also raised for safety and deck cargo considerations.

Q: Are there no previous studies on the handling arrangements for this type of rig? (Capt. R. Maharaj)

A: We always felt that a smaller test and training vessel would be needed under the project. As it has turned out, handling has not proved difficult in the latest 2.5 ton model.

Q: Why is it considered necessary to add a further mast for the larger vessel rather than increase the sail area? (Capt. R. Maharaj)

A: This was done for stability reasons and to avoid the need to move away from the standard design and adopt an entirely new rig and new sail sizes.

Ship Management and Wind Assistance

John King*

The management of any enterprise is concerned with the efficient use of resources to achieve a defined objective. For most enterprises, the ultimate objective is to be profitable. In shipping this is usually, but not always, achieved by employing ships and people to transport cargo from one point to another producing ton-miles of transportation output. Although this is obvious, it is worth saying at this time so that the overall objectives are not ignored in favor of matters of detail. And in the subject before this Conference there are certainly matters of detail, especially of technological detail, to attract our attention.

Today, the international shipping industry is facing acute problems which present challenges for management and opportunities for displaying technological ingenuity. These problems stem from a variety of causes: the sluggish world economy, the oversupply of tonnage, high fuel prices, and high labor costs, at least in the more developed countries. Although the magnitude of these problems is greatest for the operators of vessels engaged in the world's major trades, it is by no means insignificant in the less formal environment in which local and interisland trades are conducted. Indeed, one might argue that the need for effective management is as great in the latter as it is in the former.

The need for transportation is self-evident, but the objectives which ship operators hope to achieve by satisfying this need are not always self-evident. As noted above, for many enterprises the main aim is to be profitable, and supplying shipping services provides opportunities for making profit. Thus, established shipping companies may seek to manage profit and operate their ships as effectively as possible. In the last few years, however, it has appeared that more favorable conditions for making profit

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exist outside shipping, and many well known companies have directed their efforts elsewhere.

This is not to say that all shipping companies aim to make profits directly from operating their ships. For example, some have seen opportunities in the sale and purchase of ships; others have seen tax advantages in operating ships, possibly at a loss. Still others, especially state-owned or supported enterprises, are run to achieve national, economic, social, or political objectives which are not directly concerned with the need for transportation in the world at large.

Saving fuel is not a primary objective for any of these enterprises. If it were, it would be easy to achieve, simply by not running the engine. This is not to say that fuel savings should be ignored. Rather, it must be recognized that fuel is a resource which must be used, along with others, as efficiently as possible to achieve the overall objective of operating a ship. Fuel saving is not an end in itself; it is a means to an end.

The high price of fuel in recent years and the prospect of even higher real prices in the long term have focused attention on a variety of conservation measures and the potential benefits of using alternatives to oil. One of these alternatives, wind assistance, is of concern to us here. In order to assess the opportunities which technological developments in this area now offer, we must first consider the wider context in which they appear.

The development of shipping since 1945 can be divided into two distinct periods, the first ending in the early to mid seventies and the second extending to the present day. During the first period, the world economy was expanding, and shipping was concerned primarily with meeting the substantial additional demands made upon it. Technological advances were directed towards increasing transportation capacity and the benefits from these advances were reaped in the form of economies of scale. Hence large-scale operations, either in bulk or in general cargo/container transportation, tended to displace small-scale ones.

Since mid 1979 two essential changes have taken place. The first is that the rate of expansion of the world economy, and hence the demand for more transportation capacity, has fallen. The second is that the benefits from technological developments in the 1950s and 1960s, which led to a larger scale of operations, have largely been realized, so that the return from further development is now marginal. Thus, shipping companies have found themselves in a position where there is a fall in demand for their services and where, at the same time, they cannot rely on technological developments to improve their profitability.

In such circumstances survival depends upon being able to operate as efficiently as possible, keeping the ton-mile cost of operation lower than that of competitors. Technological development, if it is to be of any assistance, must be aimed in directions which will achieve this.

Reducing fuel costs is one target which is now being addressed. It is an important one; in many cases it is the most important one because fuel constitutes the major cost element in operating accounts. It must not be forgotten, however, that it is not the only one. The total cost of operating any vessel includes crew costs, maintenance and repair costs, stores, insurance, etc. and efficient management demands that all of them be taken into account.

The total cost of operating a ship should include interest on the capital invested, money which could otherwise be invested elsewhere if it had not been committed to the ship. It also includes port charges, agents' fees, charges for general administration and marketing of the services the ship makes available, commissions, and so on. Some of these relationships are indicated in the table below.

Approximate Daily Operating Costs of Ships 1984/85
(in US$ per day)

	General Cargo Ships (deadweight tons)			Small Container Vessels
	5,000	10,000	20,000	
Financial Charges (including insurance)	3,054	5,539	6,405	5,563
Containers	—	—	—	2,979
Ship Repair and Maintenance	1,200	1,260	1,440	990
Crew	2,340	2,764	2,859	1,635
Stores	165	225	247	210
Administration	900	1,080	1,170	1,192
Total Excluding Fuel	7,659	10,868	12,121	12,569
Fuel in Port	912	1,200	1,264	840
Fuel at Sea	4,800	6,720	7,440	4,800
Total Fuel	5,712	7,920	8,694	5,640
Total Daily Costs	13,371	18,788	20,815	18,209
Fuel as Percentage of Total Daily Costs	43	42	42	31

The point, of course, is that there are no simple solutions. Improving operational efficiency and reducing operational costs can be achieved in various ways, none of which is universally applicable to every type of vessel or every shipping company. And while everyone's concern about oil prices has been very much in evidence since 1973, it would be wrong to suppose that merely reducing the fuel bill would be enough. In fact it is quite easy to reduce the fuel bill: just steam more slowly. But the consequences of doing this may be highly undesirable. For example, transportation output is lowered, and capital, tied up in what is now overpowerful propulsion machinery, is underemployed. It follows, therefore, that a more subtle approach is necessary. Reducing fuel costs is an objective which must be seen in relation to the objectives of the company as a whole.

Although the circumstances of the 1973 fuel crisis and its aftermath have given it a special character in the eyes of many observers, there has never really been a time during the last 150 years or so when fuel prices have not been a subject of concern. It is true that the extent of the concern felt by ship operators has varied through the years. And this is reflected in the fact that at different times, different forms of propulsion have been adopted.

Thus, 'What is the most appropriate form of propulsion over the foreseeable life of this vessel?' is probably a more sensible question than 'How can fuel costs be reduced?' The former leads to different answers in different circumstances, whereas the latter always points to vessels which do not use fuel at all, such as sailing ships or galleys, regardless of whether or not they are able to cope with the tasks they are expected to perform.

In recent years, concern about the long-term availability of fossil fuels has persuaded some people that the prospects are bleak. In contrast, in the early nineteenth century, some ship owners were reluctant to use power driven vessels, arguing that since the wind was free, why pay for fuel? This attitude was as shortsighted as that adopted by those who would argue the reverse case today.

The fact is that at different times and in different circumstances, different forms of propulsion may be appropriate. If one traces the development of ships over the last century, one can see that the composition of the world fleet, broken down by type of propulsion system, has never remained static. Coal-fired steam reciprocating, steam turbine, diesel, gas turbine and so on have all enjoyed varying degrees of popularity according to the circumstances of the times and the objectives being sought. Moreover, many of the arguments which are heard today concerning the consequences of fuel prices, and which might seem to some of us to be addressing new problems have, in fact, been heard many times before. In the 1930s, for instance, the relatively high prices of diesel oil compared to that of coal was frequently commented upon, and it dissuaded many shipping companies then from adopting the diesel engine which now powers some 90 per cent of the world's merchant ships.

What is the most appropriate form of propulsion for ships today and in the near future? Clearly, the answer to this depends upon the sort of vessels which are being considered. Other things being equal, that form of propulsion which contributes most to reducing overall operating costs will be the most appropriate. There are many alternatives to choose from. Classifying them according to energy source we may include oil, coal, nuclear, hydrogen and wind system. Alternatively, classifying them according to machinery type we may include steam reciprocating engines, steam turbines, gas turbines, diesel, and a whole host of wind energy devices to be used either alone or in combination with other forms of propulsion machinery.

At present, all of the foregoing forms must be regarded as feasible alternatives, to some extent, for at least some types of vessels. In the future, it is reasonable to assume that the extent to which any particular alternative will remain feasible or appropriate will change.

Notwithstanding the increasing price of oil fuel, diesel propulsion remains today the most appropriate for a majority of vessels. To a large extent this is due to the considerable advances in diesel engine technology that now allow powerful and efficient marine engines to burn very poor quality residual fuels which are not much use for anything else. Much of the development which has allowed this to take place has been achieved in the last twenty years and is continuing.

More recently, coal firing has attracted renewed interest. Several coal-fired vessels are now in operation on routes where fuel is readily available.

Interest in nuclear propulsion has been long standing. For commercial vessels, however, nuclear propulsion has so far proved singularly unsuccessful and it is unlikely to play an important role in powering merchant ships in the foreseeable future. The same is true for hydrogen propulsion, although the potential here is possibly greater.

Nuclear propulsion and modern coal-fired systems are only worth considering for fairly large or powerful vessels. While diesel engines come in sizes from 10 to 30,000 horsepower, many of the advances which have contributed to their current advantages, such as the use of low grade fuel, are to be found only in the larger installations. 'What then are the alternatives for small vessels?'

The alternative form of propulsion which remains to be mentioned is that which is dependent upon the wind, either alone or in combination with others. Wind propulsion has undergone a revival during the last decade. For centuries, it was the principal means of propelling ships. During the last fifty years, however, it was absent from the world's major trade routes, although it never completely disappeared from interisland trades.

There are several reasons for this renewed interest. Technological development based on an understanding of aerodynamics, materials science, or meteorology which did not exist when sailing vessels last predominated, has been advanced by advocates of sailing or wind-assisted propulsion over the last few years. The extent to which wind propulsion devices have been accepted, however, has not been particularly great until recently. Among the developed countries, Japan has been a notable exception to this. There are now several Japanese vessels which employ wind assistance.

Most developed maritime nations have shipping industries which are long established and in consequence have well-entrenched traditions and attitudes. Radical changes, such as the reintroduction of wind propulsion, are not easily brought about here. Also, the worldwide trade in which the fleets of such countries are primarily engaged involves large ships. These are very much larger than sailing vessels which were in service in the past and may not, therefore, be ideal for experimenting with new forms of wind propulsion. Thus, the technological advances which have been achieved by aerodynamics experts and their associates have so far generally been met with muted enthusiasm.

The technological advances are nonetheless real for that, as indicated by other contributions to this Conference. They are, moreover, ones which are adaptable on a small scale.

For interisland and local trades employing very small vessels, the question of the most appropriate form of propulsion at present yields a narrow range of practical alternatives: oil engines or wind propulsion, or some combination of the two. As for larger vessels, it is necessary to view propulsion costs as part of the overall operating cost of each vessel.

For any ship, the relationship between speed and power is nonlinear. Thus, as speed increases, the power (and fuel consumption) required increases more rapidly and the marginal cost of speed thus rises. In these circumstances, wind-assisted propulsion offers the possibility of substituting wind energy for oil-derived energy at the top end of the vessel's speed range. As is demonstrated elsewhere, it may be possible to arrive at some combination in which the desired and acceptable performance of the vessel is achieved at a lower overall cost than that using an oil engine alone — provided, of course, that the ship is treated as a system.

This immediately raises two further points. The first is the obvious one that, although the wind blows for nothing the cost of harnessing it is not zero. The second is, 'What is acceptable performance?'

The cost of the various wind-assist devices is far from negligible. It may include the initial capital cost of mast, sails, control systems and such other ancillary devices as may be necessary, which must be set against any savings from installing an engine smaller than would otherwise be required.

In addition, there may be other costs which may be difficult to estimate, but which may, nonetheless, not be negligible. Examples of these are costs associated with the adaptation of the hull to suit motor sailing, or costs associated with adapting a ship's general arrangement to facilitate cargo handling with masts and sails, or foils, in place.

The definition of what is acceptable performance is not easy to arrive at. One might readily argue, for example, that mechanical propulsion is inherently a good thing simply because it allows the vessel to be operated irrespective of the effects of environmental conditions, such as, no wind, strong tide, lee shore, etc. This is a powerful argument against pure sailing ships, one which carries much weight with the operators of larger vessels. However, it is not easy to fix the level of mechanical propulsion which is sufficient to ensure safe operations but not so high as to reduce, significantly, any benefits which might accrue from the wind.

An advantage of wind-assist devices is that they can often be installed to good advantage in existing mechanically propelled vessels. Retrofitting is becoming increasingly common in small vessels. Where it is important to measure benefits in terms of fuel cost savings, when foreign exchange is not available to buy fuel, experience to date has often been favorable. This, however, is not unlike the slow-steaming policy mentioned earlier. Resources originally installed in the vessel are no longer being employed fully. Thus, in many circumstances it is probably unwise to measure the benefits of investing further in wind-assist devices simply in terms of monthly outgoings.

Nevertheless, benefits in the form of operational experience alone may be regarded in some cases as sufficient justification for sail retrofitting. Certainly, the developed world is in the curious position today of looking to the developing countries which are operating small vessels in their own local trades, to provide experience of this new technology.

There are no major technological hurdles which have to be overcome to bring about the introduction of wind-assisted propulsion on a large scale. There is, however, much fine tuning to be done. It may also be necessary to revive one or two skills in sailing which have lain dormant in most of the world for half a century. However, most importantly, the need for effective management, as defined at the beginning of this paper, remains as strong as ever.

Improved Sail Propulsion for the Country Boats of Bangladesh*

M.H. Khan and Mahiuddin Chowdhury**

INTRODUCTION

The main objective of this paper is to describe an improved sail configuration for the country boats of Bangladesh. To justify the considerable impact of any such improvement on the overall socioeconomic conditions, all features relevant to this theme will be briefly discussed.

The first part of the paper describes the physical and economic conditions of the country, together with an overall picture of the transport sector. These matters are discussed to establish the importance of country boats as a major mode of transport and the urgency of improving their technical and operational efficiencies. Following this, the construction and operation of the country boats is described as a background to the core of the paper, namely the NOAMI-I Project, where technical improvements achieved through improved sails and rigging on an experimental vessel are introduced. It is evident, however, that technical improvements confined to an experimental boat can hardly create any perceptible impact on the situation prevailing in the country. To implement these improvements to the benefit of the boatmen in particular, and the country as a whole, the NOAMI-I Project should be extended.

The costs of the technical modifications and plans for extension of the Project are also presented along with an appeal to prospective donors, particularly the Asian Development Bank, to finance the extension program.

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* Admiral M.H. Khan was Chief of Naval Staff of the Bangladesh Navy, Deputy Chief Martial Law Administrator and Minister in Charge of Ports, Shipping and Inland Waterways Transport. He founded the National Oceanographic and Maritime Institute (NOAMI) and is its Chairman.
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LAND, CLIMATE AND SOCIOECONOMIC PATTERNS

Physiographic Features of Bangladesh

Bangladesh has a total land area of 143,000 sq km of which rivers account for about 5 per cent. The topography of Bangladesh may be described as mainly a flat alluvial plain with numerous rivers and streams. Marshes, backswamps, *haors, baors* and *bils* (ox-bow lakes) break the monotony of the vast flatness. Hilly portions are found in the eastern margin of the Sylhet plains, and in the southeastern part of the country, in the Chittagong and Chittagong Hill Tracts. Bangladesh is enclosed in the north by the Tibetan massif. Here, the snowfall and rainfall over the eastern Himalayas provide the major water supply of the Ganges-Brahmaputra-Meghna river system which flows through the Lower Indo-Gangetic plain and discharges to the Bay of Bengal. These three big rivers, together with their tributaries and distributaries, criss-cross the country in a number of directions, forming an ideal network of navigable waterways. The country also has a highly irregular deltaic coastline that runs for nearly 600 km.

Climatic Conditions

Three distinct air streams affect Bangladesh. The southwest monsoon, from June to October, originating from the Indian Ocean, carries air that is warm and moist. During March to May the warm but less moist easterly trade winds prevail. Finally, the northeast winter stream comes from the bleak Siberian anticyclones from November to February. These dry, cold northeasterlies bring cool temperatures down to Bangladesh with little or no rainfall.

During the winter months (November to February), the winds are generally light over the country (Beaufort force one to two). From March to August, the speed of wind increases and generally becomes light to gentle (Beaufort force two to three), although the exposed coastal areas have higher wind speeds. The average surface wind speeds of a number of stations all over Bangladesh are given in Table 1 and the average percentage of calms and wind directions at various stations may be seen from the annual wind roses of Map 1.

Flood and Cyclone

Destructive floods are one of the most serious problems in Bangladesh. Most areas in the country have floods once every two or three years. In recent years, the situation has become worse because of increased siltation. Flash

Map 1

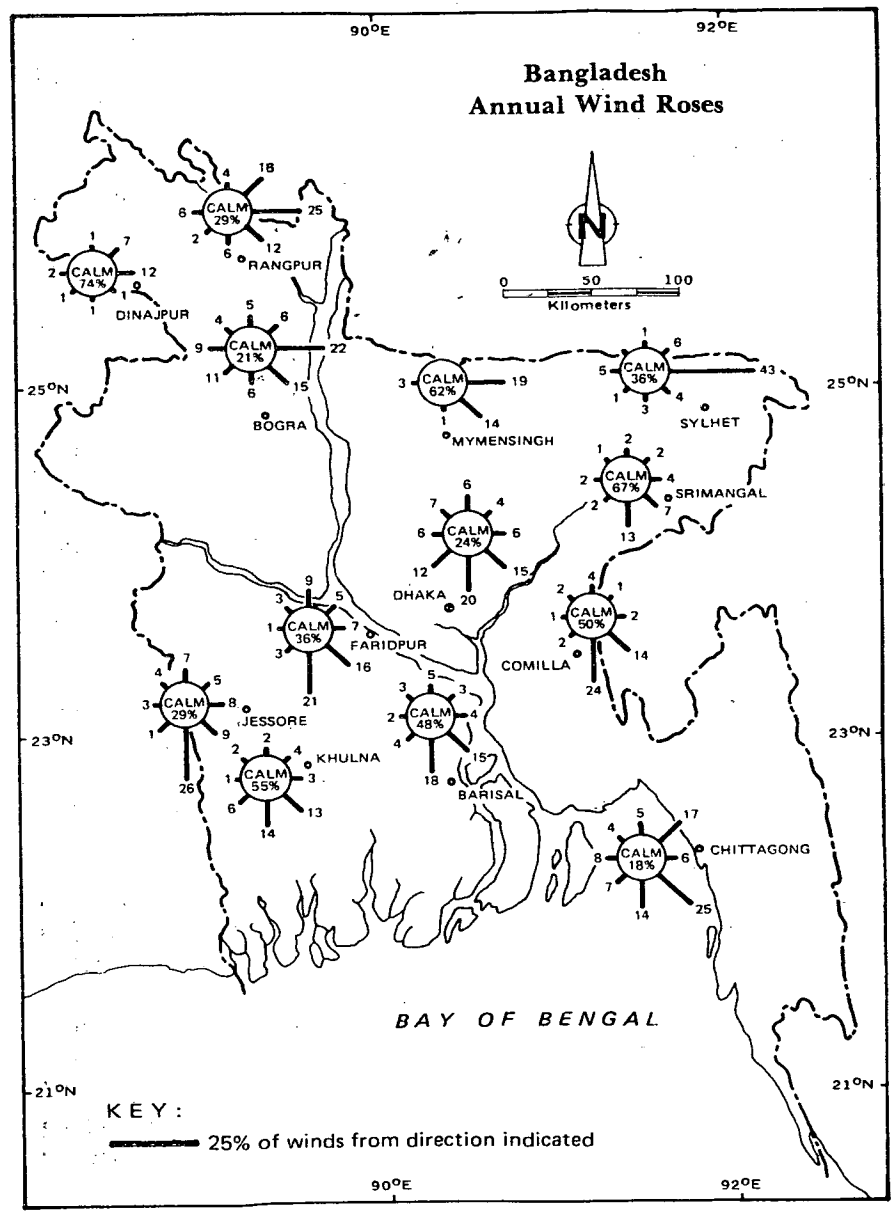


Table 1
Average Speed of Surface Wind (knots)

Station	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
Chittagong	2.2	2.3	3.0	3.5	4.8	7.1	6.7	9.0	3.1	7.1	5.4	3.2
Dhaka	2.8	3.0	2.8	3.2	5.0	7.1	8.6	7.3	7.5	6.4	6.5	4.0
Comilla	1.2	1.1	1.3	1.9	3.9	6.0	6.4	6.1	6.3	5.6	3.6	2.0
Faridpur	1.4	1.4	1.5	2.0	3.4	5.6	6.4	5.6	5.3	5.7	3.8	2.0
Cox's Bazar	1.5	1.4	1.8	2.4	3.0	4.1	4.3	4.5	5.0	4.4	3.2	2.0
Barisal	1.2	1.0	1.9	2.3	3.5	4.5	4.9	4.8	4.9	4.1	3.2	1.0
Bogra	1.6	1.6	1.7	2.0	2.7	3.5	3.6	3.3	3.0	2.7	2.3	1.0
Dinajpur	0.9	1.0	1.0	1.4	2.1	3.0	3.3	3.0	2.8	2.4	1.8	1.0

floods can occur in any of the rainy months along the northern borders. The middle of August to the middle of October is the period most prone to such floods. The other common natural phenomena in Bangladesh are the cyclones which are a permanent hazard for about 18,000 sq km of the coastal region. In Bengali they are called *Tufan* from the Chinese, *Taiphon*. April to May and September to October are the worst months for *Tufan*.

Socioeconomic Pattern

In this overwhelmingly rural but densely populated country, about 85 per cent of the total 100 million population lives in 68,000 villages. About 75 per cent of the labor force is employed in cultivating over nine million hectares of arable land, only 27.9 per cent of which are currently under irrigation. More than half of the gross domestic product comes directly from the agriculture sector. If the indirect contributions of agriculture to transport, trade and manufacturing are considered, the share of agriculture is around two-thirds of the total. On the other hand, industry contributes only eight per cent, which is considerably less than the 13 per cent for least-developed countries as a whole.

Even though capital is very scarce and labor abundant, most of the industries in Bangladesh are as capital-intensive as in the west. As a result, industries are few and only about 400,000 jobs are generated. Since this is less than half of the annual increase in country's labor force the consequence is mounting unemployment. The number of unemployed is expected to double in the next 15 years.

By all conventional standards of measurement, Bangladesh is a poor country. Gross national product per capita in 1983 was estimated at US$130, the second lowest, next to Ethiopia. The income distribution is, however, skewed. The top 20 per cent of the population accounts for about 46.9 per cent and the bottom 20 per cent for only 6.2 per cent of national income. Nearly 80 per cent of all rural households are estimated to live below the poverty line.

The most disturbing feature is that the situation is worsening rather than improving. Poverty, malnutrition and hunger are increasing and the average daily calorific intake fell by 150 k cal from 1964 to 1976. The real wages of agricultural workers are also falling, and value of wages in relation to the price of rice is in continual decline. Moreover, the conditions of sharecropping arrangements have progressively worsened and the number of landless people is growing at a rapid pace. The number of households which have no land of their own has grown from 14 per cent in 1951 to about 40 per cent today.

Proper development of the country boat sector can create perceptible, positive impact, at least on the employment situation of the rural-based unemployed who are already at or below the subsistence level. An estimated one million persons are directly, and around five million people indirectly, dependent upon country boat operations for their survival.

THE TRANSPORT SYSTEM OF BANGLADESH

Historical Background

Three different periods may be identified in the development of the transport system of Bangladesh. These comprise the period up to the partition of India (1947); the period up to the liberation war (1971); and the post-liberation period.

Before the partition of India, the British built the railways and operated the river routes with their own steamers. The entire transport system was oriented towards Calcutta during this period. The British were not enthusiastic to construct metalled roads in this part of the then India. In 1947, East Pakistan inherited just 460 km of metalled roads.

Partition brought the severance of links with India and the need to reorient and develop the transport network. Inland waterways transport weakened because most of the vessels that plied the rivers of East Bengal remained in India. The country's transport burden was largely borne by the railways, with little help from road transport. During this period, the country's only seaport was also run by the railway authority. This tendency continued until the rail lines in the northern region could no longer handle the volume of traffic.

Government efforts to improve the transport infrastructure were stepped up during the 1960s and top priority was shifted to the building of roads. Inland river ports were also built, as were new railway stations and sidings. New government organizations such as the Inland Water Transport Authority (IWTA), Road Transport Corporation (RTC), Inland Water Transport Corporation (IWTC) were also created.

The war of liberation destroyed a great deal of the country's infrastructure. However, by 1974, most of the damage had been repaired and a major expansion program initiated. After 1975, private investment in the transport sector increased considerably. Between 1975 and 1979, private investments in road and inland waterways transport were estimated to be 880 million taka and 550 million taka respectively.[1] Concurrently, the transport sector received about 17 per cent of the total public investment during 1970s.

In spite of all these improvements, Bangladesh still has an inadequate transport system. The Government itself views transport as the least-developed sector of infrastructure in Bangladesh (Revised Second Five-Year Plan (RSFYP), 1983). Transport in the rural areas is simply atrocious. About 80 per cent of the rural population has no direct access to mechanized transport and about 50 per cent of the total population has to use nonmechanized transport, or simply walk five to ten miles to reach existing mechanized facilities. The most vital nonmechanized mode is undoubtedly the country boat, particularly during the monsoon, when nearly 40 per cent of the country is inundated by flood water.

Mechanized versus Nonmechanized Modes

For the country boat subsector to be placed in its proper perspective, it is essential to discuss the relative positions of the various modes available in the transport sector of Bangladesh by grouping them into mechanized and nonmechanized modes. Based on official statistics, nonmechanized operations account for about 75 per cent of the value added by the transport sector. At the present rate of growth, it will take about 40 years before the value added by mechanized operations approaches that of nonmechanized operations.

In spite of very high priorities given to the mechanized modes, their development is slow for genuine reasons. Because of geological features, large areas of Bangladesh are a road builder's nightmare. Construction of arterial roads in Bangladesh can cost $0.7 million per kilometer. Repair and maintenance costs are also high. Although not economically viable, road building has been indiscriminately promoted for political reasons. On the

1 One US dollar is roughly 33 taka (July 1986).

part of railways, the volume of Bangladesh Railways (BR) freight traffic is steadily declining, in competition with the mechanized inland waterways and road transport. BR passenger traffic, however, has increased steadily and reached 96 million passengers in 1977-1978, its highest, but in terms of financial performance has continuously deteriorated. It is, in the words of the World Bank, a significant 'drain on resources which the Government can ill-afford.' Like BR, RTC is also plagued by inefficiency and poor financial performance.

The case of inland waterways is quite different. For the World Bank, the inland waterways transport system is a 'very competitive private sector operating under little regulation.' For the Economist Intelligence Unit (EIU), the rivers and waterways of Bangladesh are seen as 'an unchanging asset, where even modest investments could yield high returns.' The inland waterways carry over half of all arterial freight traffic and over a quarter of all passenger traffic. Nevertheless, the national budget allocation of the inland waterways subsector is not commensurate to its importance, only 8.9 per cent, as against 32.2 per cent for the roads and highways and 30.6 per cent for the railways (RSFYP, 1983).

It seems clear, therefore, that for Bangladesh, nonmechanized modes deserve more attention than the mechanized modes, at least for another three to four decades. And within the mechanized modes, the inland waterways transport subsector should get priority attention.

Nonmechanized Transport

For nonmechanized transport, it is important to note that the country boats are the single most important mode. They have a carrying capacity of about one million tons, nearly three times greater than the carrying capacity of all mechanized vessels in the public and private inland waterways subsector combined. Country boats account for nearly 60 per cent of total employment in transport. The employment generated is almost three times that of the entire mechanized modes. In spite of the importance of the nonmechanized sector in general and country boats in particular, there has been a surprising lack of official interest in developing this sector. For example, out of a total of 334 projects included in the RSFYP, 1983, only one project amounting to 0.004 per cent of the public investment in transport sector is directly linked to nonmechanized operations. (This project of the IWTA has yielded disappointing results.)

There are, indeed, practical difficulties in developing public sector projects for nonmechanized transport. Nevertheless, the fact that about 80 per cent of Bangladesh's 68,000 villages are still largely dependent on traditional transport provides a clear incentive for improving nonmechanized

modes. The scope for improvement is enormous. Many nonmechanized modes are inefficient and badly need improvement.

In recent years, however, both Bangladesh officials and aid agencies have shown a positive attitude toward nonmechanized transport. Besides the bilateral aid agencies such as the Netherlands and Norway, the World Bank and the United Nations Development Programme (UNDP) are also showing interest to invest in projects aimed at improving the efficiency of Bangladesh's traditional transport sector. The Planning Commission has already initiated modest programs with the help of Intermediate Technology Transport Consultants (ITTC) of the United Kingdom.

Country boats stand first in order of importance. However, compared with the cycle-rickshaw and bullock cart which occupy second and third positions in the nonmechanized sector, respectively, country boats have received less attention. A study of their operational and technical efficiency was, nevertheless, undertaken by ITTC (Howe and Gifford, 1981), whose report contains various proposals for improving sailing and operational efficiency. Project NOAMI-I was initiated primarily to implement these and other proposals made by a combined Dutch and Norwegian team (Dolman, 1985). Project NOAMI-I is being coordinated by the National Oceanographic and Maritime Institute (NOAMI) and jointly financed by the United Nations, Economic and Social Commission for Asia and the Pacific (UN-ESCAP), and Intermediate Technology Industrial Services (ITIS).

INLAND WATERWAYS TRANSPORT

General Features

A vast amount of water flows through Bangladesh from India. In addition, rainfall in Bangladesh (less evaporation, evapotranspiration and deep percolation) adds considerably more. This mass of water flows out to the Bay of Bengal, mainly through the Lower Indo-Gangetic delta through a large network of rivers, streams and canals totaling at least 24,000 km in length. As already noted, another estimate shows that the total area of the permanent water surface is about 8,000 sq km. In the middle portions of the south region (Patuakhali and Barisal), the waterways are so plentiful that they form a veritable maze. The extent of these waterways is greatest in the southeast of the southern region and least in the northwest of the northern region.

The study of the inland waterways transport system is essentially the study of Bangladesh's vast and complex river system. The combined flow of rivers is about 140,000 cumecs during monsoon periods. During the dry winter season, this flow decreases 20 times to only about 7,000 cumecs. Aside from wide seasonal variations in flow, there is evidence that flow has also significantly reduced in the Ganges, over the past 10 to 15 years. The river network of Bangladesh is shown at Map 2, which indicates that almost the entire network is connected to the three major river systems: the Ganges (called Padma in Bangladesh), the Brahmaputra (called the Jamuna), and the Meghna. These rivers meet in Bangladesh to form the world's largest delta (60,000 sq km). Indeed, the waterways of Bangladesh are her pride.

Inland Waterways Routes

The several thousand kilometers of rivers and canals are in fact the lifeblood of Bangladesh and her people. They have traditionally been the main arteries along which passengers and all types of cargoes have been transported. The IWTA statistics show that there are about 5,300 km of navigable waterways during the monsoon. However, if the tidal creeks and channels navigable only by country boats are included, the figure exceeds 8,000 km. During the dry season, the main network shrinks to about 3,500 km.

Based on relative economic importance and to facilitate conservation and maintenance, IWTA has classified navigational routes as follows:

Class I: Main arteries of traffic flow for which a minimum depth of 2.0 to 4.0 meters are maintained throughout the year. Six Class I routes connecting the main ports of Chittagong and Chalna and the inland ports of Dhaka, Narayangonj, Barisal, and Khulna have a total length of about 600 km;

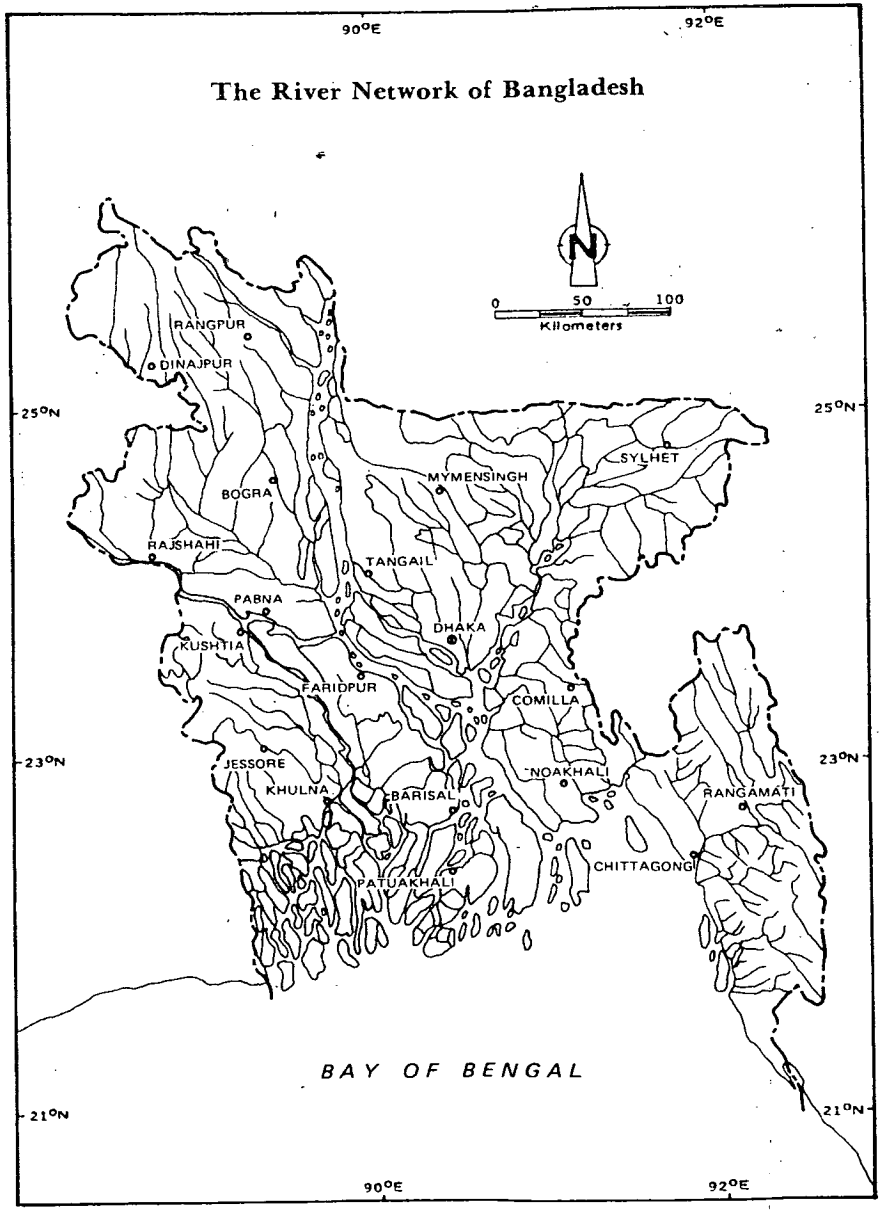
Class II: Secondary routes provided with navigational aids and maintained at depths of 2.5 to 3.0 meters. The total length of seven such routes is about 1,500 km. The specified depths are not guaranteed by the IWTA; and

Class III: Feeder routes of regional importance, for which IWTA provides periodic inspections and route map surveys. Specified depths of most of the 14 such routes are 1.0 to 2.0 meters.

Deterioration of Inland Waterways Routes

During the last 10 to 15 years IWTA routes have considerably deteriorated. This deterioration is caused mainly by the change of flow patterns of the three major rivers. These rivers are officially classified as either unstable (the Meghna) or, very unstable (the Padma and the Jamuna). River

Map 2



instability causes serious problems for the navigation. A channel that was navigable one year may not be navigable the next year.

The more serious problem, which has a direct effect on navigation, is the process of massive siltation at a progressively higher rate. The main causes of the worsening siltation problems are the following: the increase in volume of sediments carried by the river system, the reduction in river flow because of the withdrawal of water for irrigation in India and Bangladesh, and the construction of dikes and embankments in the coastal regions. In spite of substantial dredging efforts by IWTA of 17 million cu m from 1975 to 1982, there has been alarming deterioration in available water depth during the dry season. Waterways with more than 2.0 meters available depth declined in length from over 3,500 km in 1973 to only about 1,300 km in 1979.

This deterioration is attributable, in part, to the withdrawal of water at Farakka in West Bengal. There can be no doubt that the 2,200 meter Farakka barrage has had serious consequences for the Padma river regime. Before the opening of the Farakka barrage, the Padma could be navigated by large steamers in the dry season. Today, dry season flows are less than 750 cumecs while the minimum requirements for such navigation is 1,700 cumecs. In little more than a decade, many important river routes once open to mechanized vessels have had to be abandoned. Such routes include the following: the Dharla and Tista in Rangpur, the Old Brahmaputra in Mymensingh, the Jamuna from Serajgonj to Nunkhawa on the border with India, the Dhaleswari and Lakhya in Dhaka, the Karatoya in Pabna, Bogra and Rangpur, the Garai in Kushtia and Jessore, and others.

From the foregoing discussion, it may be concluded that the length and depths of the inland waterways network will continue to decrease. In spite of substantial dredging, opening of new routes for mechanized vessels will be extremely difficult, if not impossible. On an increasing number of rivers, only the shallow draft vessels will be able to ply. Obviously, for Bangladesh, this means country boats will assume an importance that has not yet been afforded them.

BOATS AND METHODS OF CONSTRUCTION

Number and Types

Although a 1977 survey reveals that there are over 700,000 small informally operated country boats in Bangladesh, a 1974 transport survey based on a series of assumptions, estimated the total fleet of cargo vessels

with over 30 maunds[1] capacity, at 63,300 vessels. The sail propulsion devices reported here are primarily for this type of commercially operated, cargo-carrying country boats, constructed in traditional designs. All cargo-carrying country boats may be classified into two groups, seagoing and inland waterways, the latter category being by far the most numerous.

Structural Features

The inland waterways boats can be divided into four groups on the basis of their construction, as follows:

(i) The round-hulled, smooth-skinned boats with raised pointed ends *(goloi)*, usually with overhangs and no keels. These boats are constructed of planks laid edge to edge and clamped together with metal staples. Frames are usually in three parts and inserted after the planking is almost complete. This group of vessels, called *binekata* type, is by far the largest and comprises the great majority of the country boats. *Buchari, bhedi, panshi, palowary, ghashi, patam, batni* and *raptani* type boats all belong to this group;

(ii) A smaller and less varied group of boats, of similar system of construction but with planks overlapping at the seams, with upper instead of lower edges of the planks overlapping outwards. This is the reverse to the common form of European clinker construction. These boats are known to the boatmen as *digkata type*. It appears that they are built only in the Sylhet and Khulna districts. Some of the larger boats are among the best-constructed of all the inland waterways boats of Bangladesh;

(iii) A small group of flat-bottomed boats which are locally named *kosha;* and

(iv) Dugout boats, of various kinds, carved from a single log.

On the basis of the construction features, the seagoing boats may be classified into two main groups:

(i) Dugouts and plank-extended dugouts, the common names of which are *kuda, shargona* and *balam*. The sewn plank-extended dugouts of Noakhali and Chittagong have probably reached the most developed form of this type of construction in the world today.

(ii) A group of flat-bottomed, hard-chine, transom-sterned boats built of edge joined planks. These boats are known locally as *Chittagong sampans*.

1 (1 ton — 27.22 maunds).

Construction Materials

For making the hull, masts, rudder, oars and sometimes the shelter roofs, considerable quantities of wood are needed. Although nearly 20 different varieties of wood have been identified in the construction of country boats, the following four types are considered the most suitable: Burmese teak, *sal, jarul* and *sundari*. The first three types are well-known for their durability in water, but unfortunately these species have virtually disappeared in Bangladesh and substitutes of inferior quality such as *sundari, gajarim garjan, shilkoroi, koroj,* are now being used in boat building. The relative strengths of some of these wood species to Burmese teak are given in Table 2. The building and operation of country boats are constrained by the increasing shortage of good quality timber. Even the second grade timbers are becoming scarce and their price has gone up by more than five times in the past ten years.

Table 2
Strengths of Some Wood Species to be Used for Boat Building in Relation to Burmese Teak

Wood Type	Weight	Strength	Stiffness	Shock Resistability	Shear	Hardness
Burmese Teak (Tectona grandis)	100	100	100	100	100	100
Jaruk (Lagerstroemia Speciosa)	95	80	85	85	100	105
Sal (Shorea robusta)	130	120	125	145	145	160
Sundari (Heritiera minor)	150	110	130	130	150	175
Garjan (Dipterocarpus turbinatus)	110	95	115	100	105	90

Source: Troller, 1941.

Aside from wood, the other materials used in boat construction include bamboo, iron, jute rope, plastic paper, oil and tar, cowdung and firewood. Bamboo is available all over Bangladesh and is used for the shelter roof, masts and oars for small boats. Iron products include nails, staples (locally called *patam),* wires and anchors. The plastic paper is used to make the roof waterproof. Considerable amounts of jute and/or nylon ropes are used as lines and backstays. A special oil called *maitya tel* is applied on the wood above the waterline and tar is used below. Firewood or dry cowdung is needed to heat those planks which have to be bent. Wet cowdung is sometimes used to join the planks.

Propulsion Modes for the Country Boats

Four motive forces can be identified: wind, current, tide and manpower. A boat will normally be able to use all these forces but not simultaneously, not in the same place and not in the same season.

Tide Power

The tide effect is quite prominent in the southern districts of Khulna, Barisal and Patuakhali where the rising and falling tides create strong currents upstream and downstream respectively. During the dry season the tide effect is more significant. For navigation inland, north of the confluence between the Lakhya and the Brahmaputra, the importance of tide is for the rise in the water levels rather than currents. In fact, many of the feeder routes are navigable by country boats only during high tides.

Current Power

The current of the river flow, as a motive power, works only downstream. In the monsoon months (June to September) when there is a large discharge, strong currents make the downstream trip an easy one.

Wind Power

The picture is more varied with regard to wind. Prevailing winds tend to change both speed and direction almost every month. In the dry season (November to January) the winds in the central parts of Bangladesh are northerly but weak. From February, the wind tends to blow from the south and this wind is perfect for sailing upstream. In August, the wind gradually decreases and by October, light winds from both north and south are experienced.

The influence of these natural forces on country boat propulsion may be summarized as follows:

(i) Some months are more favorable for traveling by boat than others;
(ii) Upstream travel becomes easy or difficult depending on the season;
(iii) On a round trip, boats will have to combine several modes of locomotion;
(iv) The best months for making a round trip are from mid-June to mid-August. The current provides very good downstream drift, and the steady and strong southerly wind assists the boats upstream; and
(v) The worst months for a round trip are from mid-September to mid-November. The wind is light northerly, flooded river banks prevent towing, and a strong current makes it almost impossible to propel the boat upstream.

Manual Operations

In any round trip, natural forces are supplemented by manpower in propelling a boat. A striking feature is that the elements tend to work directly with or directly against the boatmen. The most demanding operation is towing. The boatmen walk at a steady pace along the tow path, pulling the boat by towlines attached to the top of the mast. The men pull the line by holding a bamboo stick across one shoulder to the chest with one hand, and by holding a small auxiliary rope attached to the towline with the other hand. In fact, the manpower requirements for towing is the main factor in deciding on the size of the crew. The other important manual tasks include rowing, poling, and sculling. The boat is almost invariably rowed by men standing or sitting in the bow of the boat. Some of the largest boats are also rowed by men standing on top of the *chauni* (the shelter). Sculling is the twisting movement of the steering oar with its broad blade, long loom, and short tiller handle. The *majhis* (helmsmen) are masters in the use of this device. Many boats from the areas where the rivers and lakes are shallow are fitted with poling trackways on either side and are rowed only for long voyages on the deeper streams.

Sailing Vessels in Bangladesh

The sails of an inland waterways country boat are considered an auxiliary means of propulsion. The wind is a welcome but occasional help to

provide breaks, sometimes long breaks, in the drudgery of rowing, sculling, poling, and towing.

The rigs are either some form of square sail, or sprit sail, and all are single-masted. Except for the smallest boats, the masts are stepped in a tabernacle and pivot on an iron pin without a counterweight. The yards of the smaller boats are rough hardwood or bamboo poles. Those of the larger boats are made up of two or more poles lashed together. For example, the *palowary* from Dhaka region usually sets a deep square sail with a narrow topsail above it, whereas the large fishing boats of the Padma have a square-cut sprit sail. Rigging is very simple and is made up from hand-twisted jute rope and has no permanent stays. Often there are only two braces and the halliards are sometimes led aft as backstays. The larger boats have two backstays set up with tackles. The yards are not fitted with parrels but hung from the halliards drawn up tight to blocks at the front of the mast. No jibs or auxiliary sails of any kind are used. Sails are never reefed, and there is no provision to do so. Many of the larger boats carry a shallow topsail above the square sail but never a top gallant sail. The sails are made of light cotton material and are often patched and mended or sometimes left with great rents in them. It is a common scene to see boats sailing with more holes than sails between the bolt ropes.

The most important point to note here is that the spoon-shaped hull of the country boats, under full bellying sails, can never sail to windward. The whole idea of windward sailing is completely foreign to the river boatmen of Bangladesh. Since the river boat cannot sail to windward, and since at some seasons winds tend to blow for weeks in one direction, the river boat must furl her sails, lower her mast and proceed by some manual means such as rowing, sculling, poling, and towing. All of these modes are arduous and cannot be sustained for long periods.

The primary objective of the NOAMI-I Project was to develop an improved sail configuration to overcome this difficulty in windward movement. This objective has been successfully achieved as will be described in a later section.

Sails of Bay-Crossing Boats

The *balam* is a seagoing vessel, and her rigging is stouter and more complex than that of the inland waterways country boats. She has numerous shrouds and backstays, and a forestay. With her long narrow hull and well cut sail, the *balam* can make some sort of a showing to windward, but only if handled by an expert crew. On the other hand, the larger *sampans* set a kind of lanteen sail. The mast is stepped in a tabernacle and is supported by a forest of shrouds and backstays. The *sampans* of the two larger kinds regularly work to windward when deeply laden. In reasonable weather, this

exceptional type of boats can also approach speeds in excess of five kph on a sailing voyage from Cox's Bazar to Chandpur.

Manpower Requirements and Economics of Operation

Employment Generation

The country boats are labor-intensive for the obvious reason that they are not mechanized. With speed and other factors taken into consideration, a comparison can be made of employment generated by the three competing modes, the country boat, the truck and the cargo launches.

Let C = average carrying capacity (in tons)

N = average number of employees excluding those needed for loading/unloading

S = estimated operational speed (kph)

The ton-km of cargo transported is computed at C x S (per hour). Hence, the man-hours required per ton km $= \frac{N}{C \times S}$

The man-hours required per ton-km is the estimated labor intensity (J). The labor intensity figures for these three modes are shown in Table 3.

Table 3
Employment Generated by the Three Principal Transport Modes

	Country Boat	Truck	Cargo Launch
Average carrying capacity, C (tons)	15	9	150
Average no. of employees, N (men)	4.7	3	11
Average operational speed, S (kph)	2.5	32	11
Labor intensity J = N [C x S] man-hours per ton-km	0.12533	0.01042	0.00667

These crude estimations show that the country boats are 12 times more labor-intensive than trucks and 19 times more labor-intensive than private cargo launches.

The Boatmen and Their Income

The boatmen, called *mallah*, are generally poor people with little or no agricultural land. A few decades ago, the income earned by the boatmen was generally higher than that of the agricultural wage laborers. During the last 15 to 20 years, however, the income of agricultural wage laborers has caught up with that of the boatmen. Nevertheless, the number of people seeking to join the country boats sector is now probably higher than ever because more people in the rural areas have no land or employment. The total number of unemployed in the country is believed to be about 12 million. With relatively little seasonal fluctuations, boatmen in a commercial, cargo-carrying boat earn, on an average, only eight taka per day, plus food. The average daily wage rate of agricultural laborers for 1979-1980 is 12.53 taka and no food. In both cases, this level of income is well below accepted standards of the poverty datum line in Bangladesh.

Country boats are the least expensive of all nonmechanized modes of transport. Since the haul-length for country boats is comparatively much longer, however, comparative cost is not the sole criterion. Direct comparison of transport costs by country boats and other modes is difficult because of the lack of data.

Taking into account the labor-intensive nature of country boat operations, the abundant supply of labor and scarcities in the national economy (for example, diesel), real economic cost estimates will show a much more attractive picture of the country boat sector. The country boat sector is a fitting example of an activity that is labor-intensive, requires no state subsidy, has practically no import content, and relies entirely on skills developed locally. It would therefore be unwise to judge the sector's performance entirely on the basis of conventional cost criteria.

Unequal Competition and Effects on Employment

Because of large public investments and subsidies given to the mechanized modes of transport, the country boats are facing increasingly tough competition. In addition, the country boats are discriminated against in several ways:

(i) Jute transport contractors are often told explicitly by the mill owners that they will be paid about 15 to 30 per cent more if jute is transported by mechanized vessels rather than by country boats;

(ii) Fees for insurance which is compulsory are four times higher for country boats than for mechanized vessels; and

(iii) The country boats do not receive any compensation while waiting for a cargo handling berth. The mechanized vessels are entitled to compensation for such delay and consequently receive priority in berthage.

Moreover, it is not easy for country boats to switch from one particular trade and route to new types of commodities or new areas of operation. Hence, there is unequal competition from an expanding mechanized fleet which results in unemployment for boatmen.

As a rough estimate, it has been shown that the opening of Baghabari port to mechanized vessels has resulted in the loss of jobs, in the transport of jute alone, equivalent to 200 manyears. However, many country boat owners maintain that if they could supply jute to the mills more regularly, they would become more attractive to transport contractors. This regularity can be achieved if the following measures can be taken:

(i) Improved harbor facilities;

(ii) Towing by mechanized vessels to help navigate difficult areas; and

(iii) Improved design of sails with full provision for windward movement.

Mechanization of Country Boats

The mechanization of country boats was considered by Rahman (1968) to be the most economic alternative for the planned development of transportation. Accordingly, starting in 1970, IWTA initiated two schemes that would lead to the mechanization of 600 cargo and 500 passenger boats. The initiative under USAID funding was brought to an abrupt end by the War of Liberation. Impressed by Thailand's success with similar mechanization, IWTA commenced a second mechanization pilot project in 1978, under which three Thai engineers would be positioned in Bangladesh for three months for engine installations and training. The objectives of the second pilot project were threefold:

(i) To experiment with engines and with the system of line-towage;

(ii) To mechanize 17 country boats of various types; and

(iii) To repeat, if successful, such a venture throughout the country.

So far, the mechanization project has cost Bangladesh 43 million taka, but its results bear hardly any relationship to the amount of investment put in. For various reasons, the valuable Thai experience never found its way into the project.

However, the most important understandings from the above project are as follows:

(i) Mechanization is beyond the financial resources of the average boatman;

(ii) Towing by mechanized vessels, particularly in difficult spots, is a more attractive proposition for Bangladesh than wholesale mechanization. By this means, one towing boat can serve a large group of cargo-carrying country boats; and

(iii) Another possibility, yet to be tried, is to develop suitable sail-motor propulsion. Under this system, a small inboard diesel engine will be installed for operation only under adverse wind conditions, when the improved sail rig is not able to provide the necessary motive power. The engines to be used for this purpose are not manufactured locally.

Notwithstanding the IWTA's failure with wholesale mechanization, over 3,000 traditional vessels are now mechanized. These vessels are mainly fishing boats and bay-crossing craft which carry commodities of high value, especially fish, or which form part of an organized trade by mechanized bay-crossing boats. The cost of modifying and operating those boats is less than the resultant earnings. Furthermore, bank loans are available for the larger boats to cover engine installation costs.

For traditional country boats, modernization is necessary, but this modernization does not necessarily mean mechanization. The NOAMI-I Project is aimed precisely at such modernization without wholesale mechanization of the country boats.

THE NOAMI-I PROJECT

Introduction

One of the most important objectives of setting up NOAMI was to conduct research projects related to marine science. In this context, only those projects that will bring immediate benefits to the people of this region are considered. Aware of the crucial position of country boats in the national economy, NOAMI took as its first project, Wind Propulsion of Country Boats and River Craft.

Funding for the Project was obtained through UN-ESCAP, Bangkok, and ITIS of the United Kingdom. The UN-ESCAP funds, which actually came from the Japan Marine Machinery Development Association (JAMDA)[1], were used to finance the construction costs of the research boat (NOAMI-I) and to meet crew costs and all other local expenses. ITIS financed the costs of consultancy work. Having already acquired a good knowledge of the boats and their operation, Gifford and Partners were chosen as consultants for the Project.

Limitation of Traditional Boats

The sailing performance of traditional boats is limited by both the hull form and the sails. Most significantly, for efficient sailing, the hull must be capable of generating lateral forces to balance forces produced by the sails. The traditional boats with their very rounded hull shapes and complete absence of keels are extremely deficient in this respect. Also, to obtain the best all-round sailing performance, the sail should be trimmed along the center line of the hull and made flat in shape. This is generally not possible with the commonly occurring square sails, although on certain small boats, attempts are sometimes made to achieve these objectives. Because of these limitations, the traditional boats can only sail effectively with the wind behind them. Even to sail with the wind from the side is very difficult and sailing into the wind is generally impossible. Finally, the area of sail carried is often very small for the size of vessel, particularly when loaded.

Project Objectives

The objectives of the Project are:

(i) To design practical improvements in rig and hull design which could be fitted to existing boats, using local skills and materials;

(ii) To modify a trial boat in accordance with these designs;

(iii) To undertake sailing trials to evaluate the handling characteristics and performance of the modified boat; and

1 JAMDA was also responsible for the successful development of technically sophisticated sail assistance for modern Japanese ships (see Dr. Hamada's Conference paper on this subject).

(iv) To evaluate the economics of such modifications in terms of increased capital cost and the potential for increased revenue earnings.

Development of Modifications

From the inception of the Project, NOAMI members recognized the need to provide modifications that would allow the boats to sail against the wind. It was proposed initially that, following the example of racing yachts, a Bermudan (triangular) sloop rig should be fitted, in place of the traditional square sail. After taking into consideration the requirements of total sail area and spar sizes, as well as sailing efficiency, NOAMI members decided on a rectangular sprit mainsail with a triangular foresail. A topsail and flying jib were also proposed, to provide additional sail area for use in light winds. In accordance with these decisions drawings were prepared for manufacture of the sails. Figures 1, 2 and 3 show these sail configurations, which provide a working sail area comprising mainsail and foresail of 75 sq m. With mainsail, topsail and flying jib, the total sail area is 123 sq m. Experiments with a gunter rig were also carried out. This sail was found ideal for sailing into the wind. For sailing against the wind, it is necessary to reinforce the mast and rigging and a drawing was prepared to show the layout of rigging, attachment details and spar sizes (see Figure 4).

For the hull to generate adequate lateral forces for sailing against the wind, some form of keel or appendage was required. Draft limitations discounted a fixed keel and the need for ease of fitting to existing boats discounted a center-board. Accordingly, it was proposed that leeboards be fitted. Traditionally, the country boats are steered by oars slung over one side or the other at the stern. Instead of this arrangement, a permanent center line rudder was fitted, to be controlled by a long tiller. This modification was designed and executed by NOAMI staff (see Figure 5).

The type of hull selected was a *bachari*. This type was selected after considering loading capacity, commodity specialization, route pattern, and economic viability. Some variations of *bachari* are found on almost all major routes. *Bachari* from the Barisal area are strongly built and are used mainly for transportation of heavy commodities such as *sunderban* wood, firewood, sand and other building materials. This type was mentioned as having potential for technical improvements by both Greenhill (1971), and the Intermediate Technology Consultants (1981).

Sailing trials conducted by Gifford and Partners showed that, contrary to conventional wisdom, the sprit sail rig could be more efficient than the Bermudan rig. In addition, the rectangular sail plan allows more sail area to be carried for a particular mast length. With the locally available spar

Figure 1

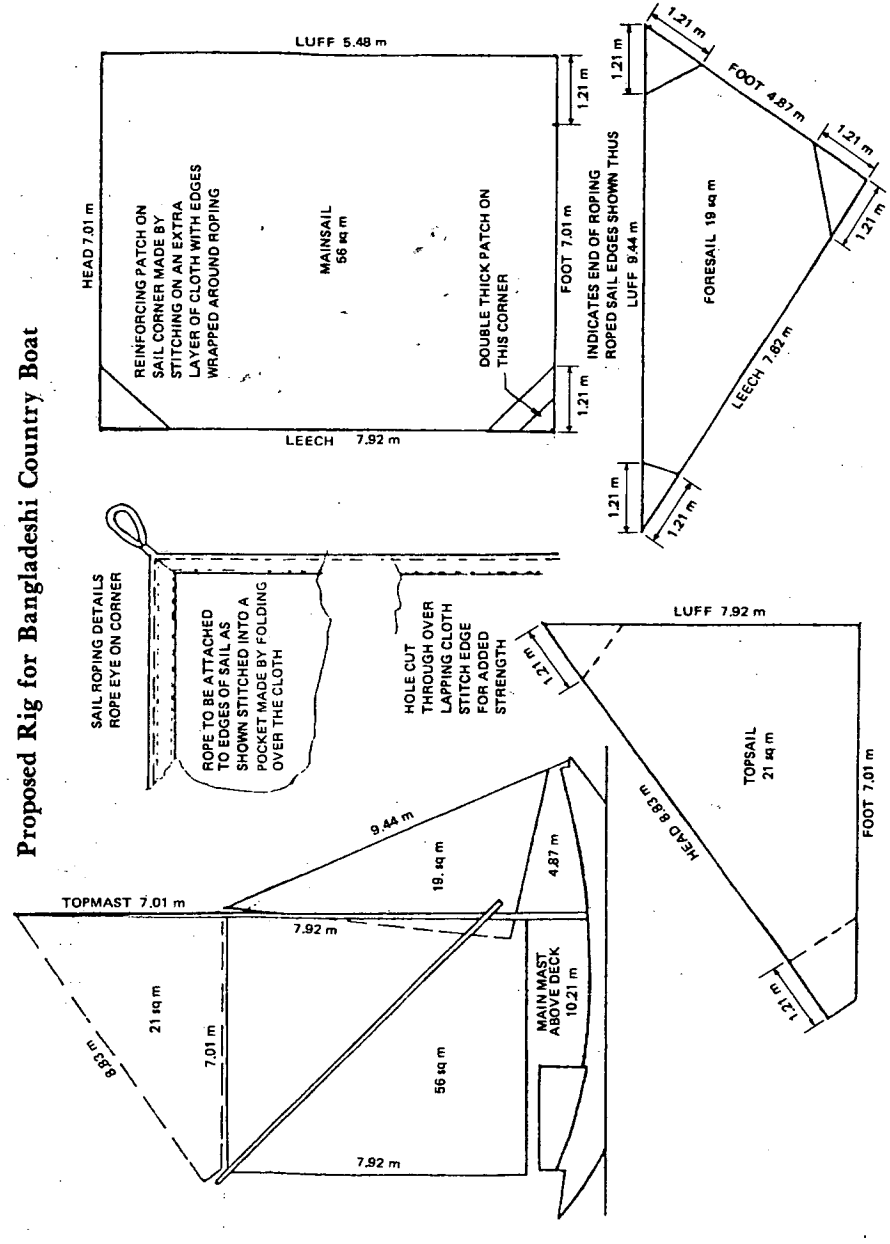


Figure 2

Flying Jib
NOMINAL AREA 55 SQ. M
FOR NOAMI-I COUNTRY BOAT

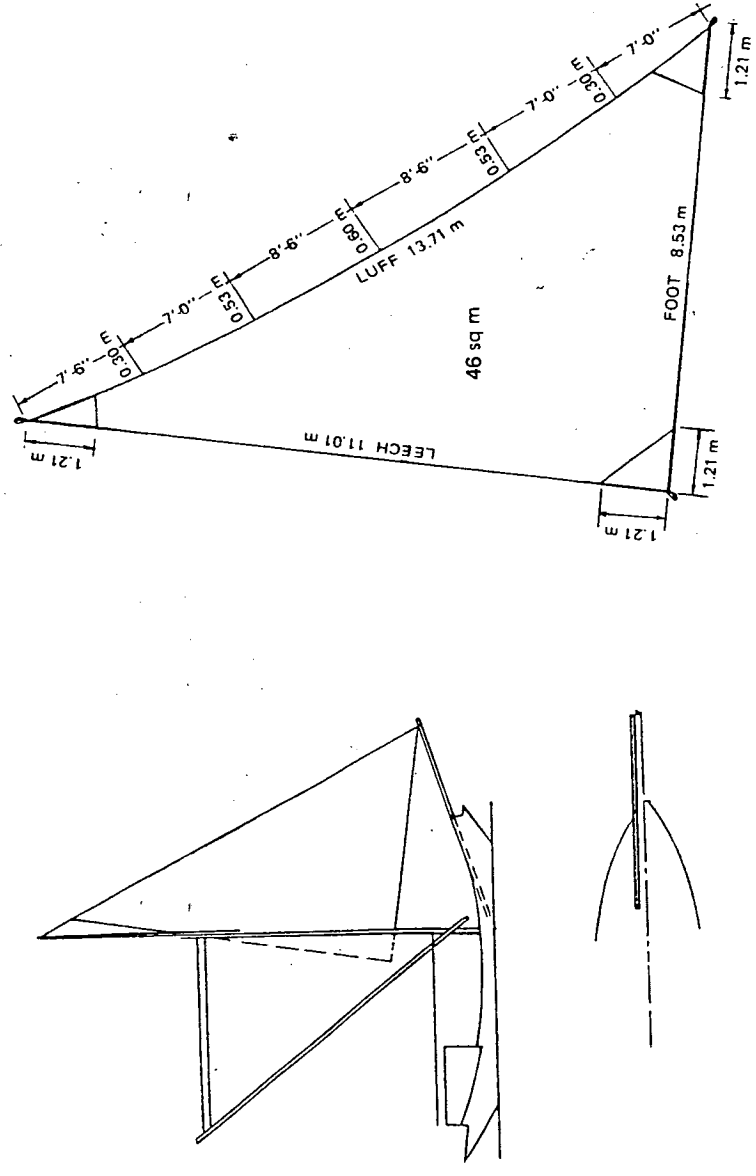
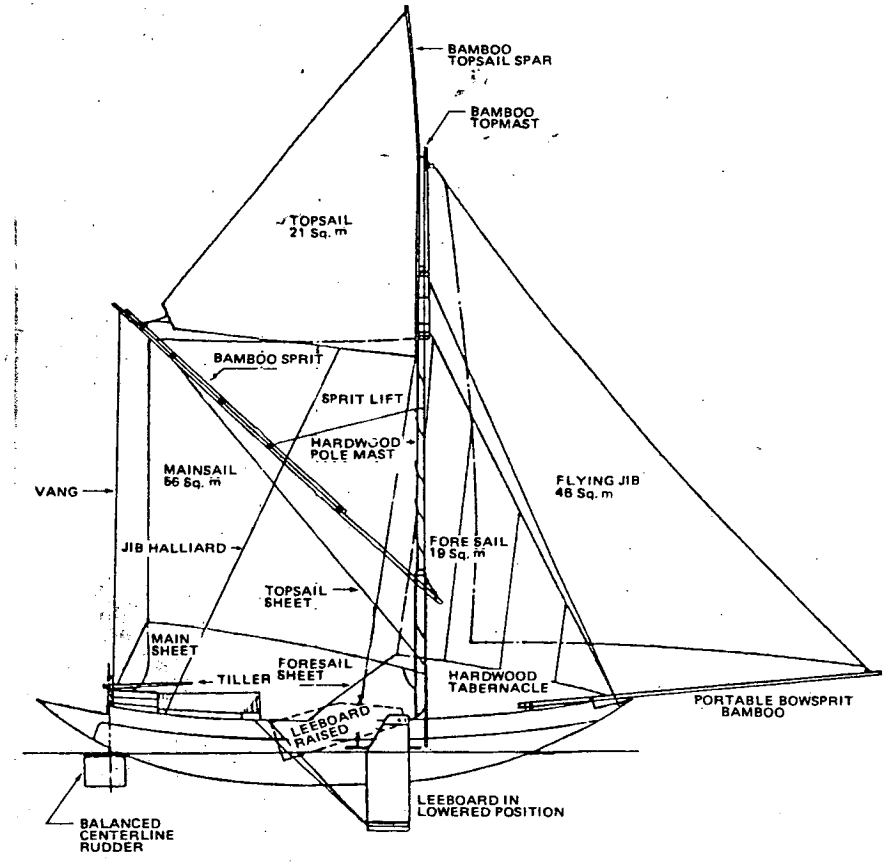


Figure 3

Developed Sailing Rig



RIG	SAIL AREA
MAINSAIL PLUS FORESAIL:	75 sq m
MAINSAIL, FORESAIL AND TOPSAIL:	96 sq m
MAINSAIL, TOPSAIL AND FLYING JIB:	123 sq m

Figure 4

Rigging Plan

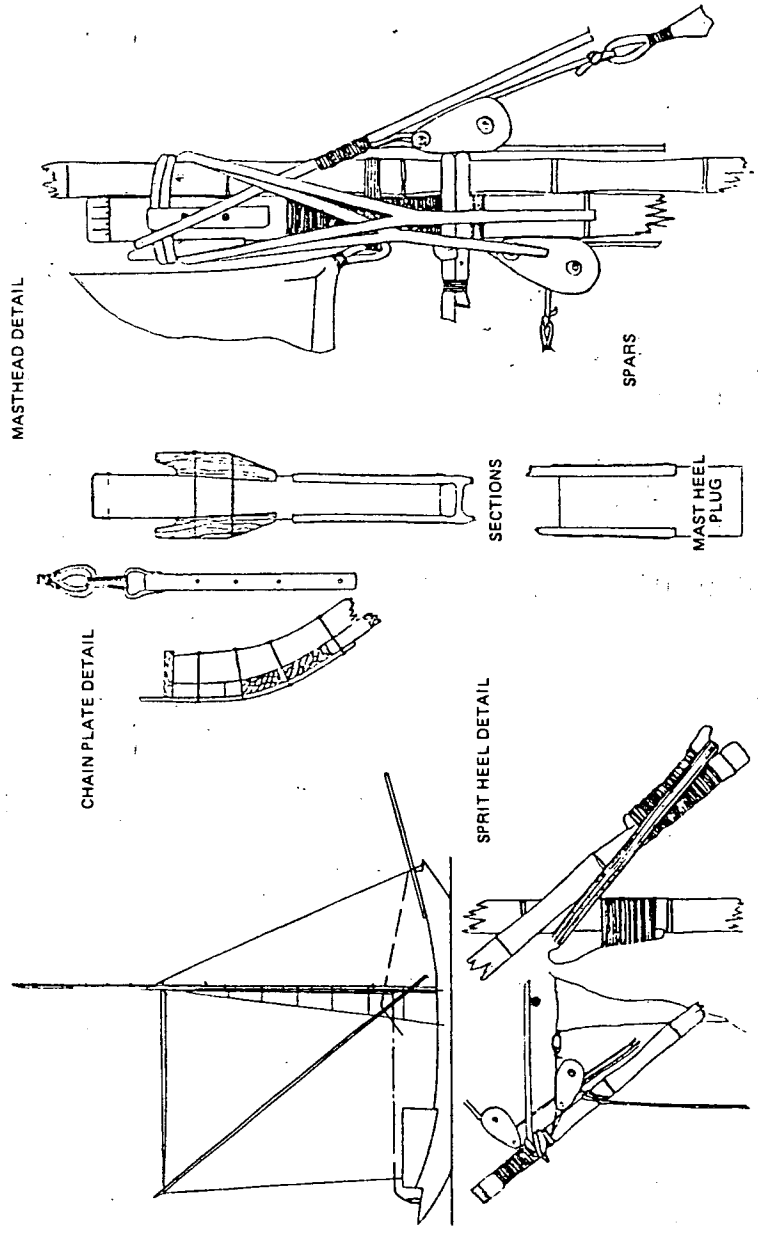
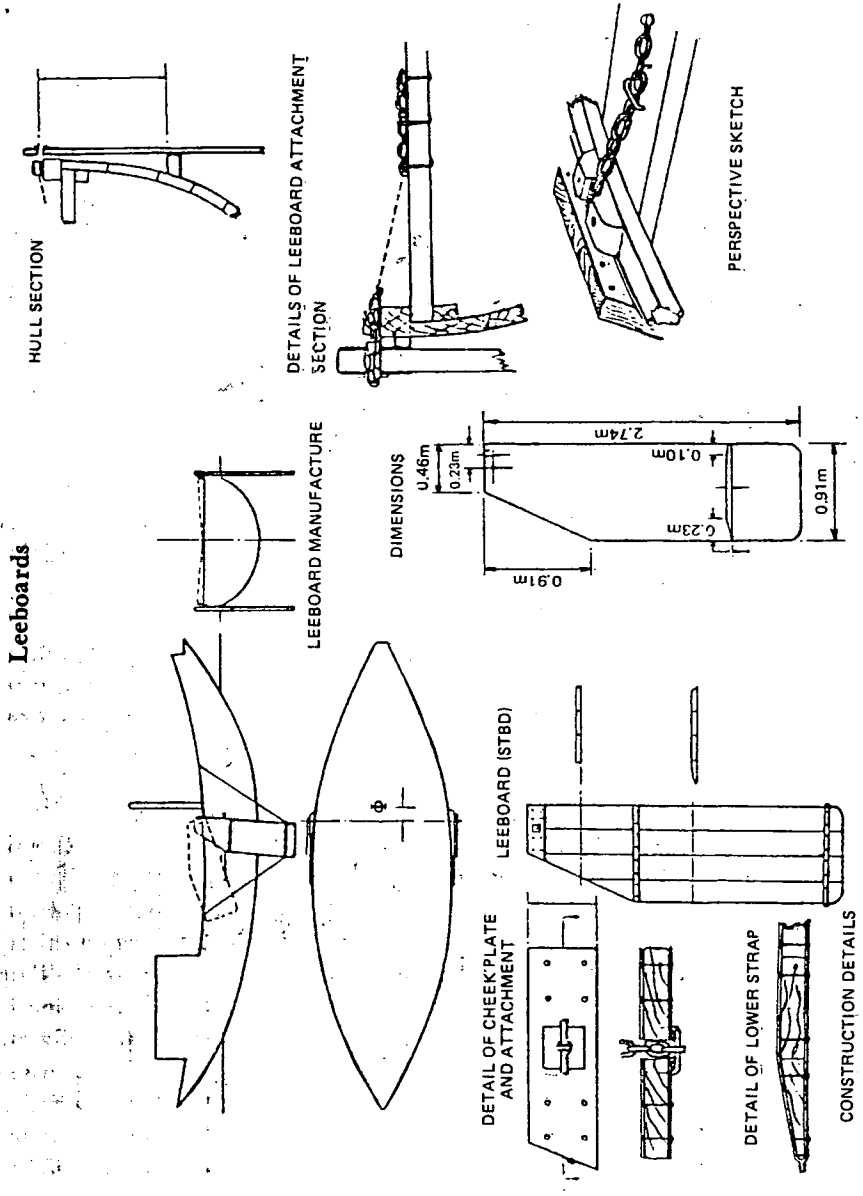


Figure 5

Leeboards



and rigging materials limiting mast length, the compact sprit sail rig was considered to be the ideal choice. Trials were also carried out with a whaler rig, further modified to a gunter rig. The sail displayed a good sailing performance and tacking was smooth, even in light winds.

Construction and Fitting Out of NOAMI-I

Hull Construction

The design and construction of the experimental vessel was undertaken by NOAMI, which placed the work in the hands of an experienced boatbuilding *mistri*, Mr. Santosh Kumar. The boat was built in traditional style using the characteristic stitched plank, *binekata* method of wooden construction which is common in Bangladesh.

The dimensions of the experimental vessel are:

Length overall	13.0 meters
Beam	3.7 meters
Depth amidships	1.5 meters
Capacity (fully loaded)	16 tons

Facilities and a site for construction were kindly provided by Mr. Rafiul Alam, Managing Director of Alamnagar Dockyard, Dhaka. The keel was laid on 27 April 1984 and the hull was launched on 19 September 1984.

Fitting Out

These sails were made of good quality cotton by a leading industrial tarpaulin and tent manufacturer in accordance with drawings by the Consultant, Mr. Colin Palmer of Gifford and Partners. Manufacture of the mast and rigging was not so straightforward. For a powerful sail, as envisaged, bamboos of specified size and strength were not readily available. Thus, three smaller bamboo poles were lashed together in a bundle and used as a mast. The rope work and general boat work was very successfully and capably undertaken under the leadership of the sailing master, Mr. Wased Ali, a full-time employee of NOAMI. The leeboards were constructed by the dockyard technicians in association with the NOAMI researchers. Some changes in detail were made but no major problem arose. In future, lighter construction would be well worth a try.

The remainder of the fitting out was carried out by the local crew after the departure of the Consultant. Many adjustments were made to the sail

attachments to improve their fit. Also, a new bowsprit was built since the first one was too flexible. The leeboards were fitted and made operational and many other details such as cleats and rowing blocks were fitted in place. Finally, a shelter of bamboo covered by bamboo matting was fitted and the boat was loaded with over 100 sandbags to provide ballast and to simulate cargo.

Sailing Trials

The first trials were conducted on the Buriganga River in Dhaka. Considering the light and variable winds which never exceeded Beaufort force two, coupled with the high density of river traffic, the trials were satisfactory. However, it was extremely difficult to explain and teach new sailing techniques in such variable conditions. After a few days the boat was moved downstream to an open stretch of water at Pagla. In conditions of more open water and steadier winds (although still extremely light at about Beaufort force two), the crew soon began to perfect the skills needed to sail effectively against the wind. They quickly assimilated the techniques needed for handling the leeboards and sail sheets when tacking and learnt the need to keep the sails drawing. The large, light jib was used on most points of sailing, although to windward it could be used effectively only in the very lightest winds of force one. In winds of only force two, the sail sagged under load and became too full to be used when close-hauled. On reaching and running courses, however, it was very effective. This proved to be a very useful working sail which set well when sheeted through the aft shroud plate eye.

Difficulties were initially experienced in making the mainsail set well in any but the lightest winds because of the excessive flexibility of the bowsprit and the difficulty of arranging an effective sheeting position. As a first step, a complete cloth was taken off the leech of the sail. This allowed the bowsprit to be shortened and improved the sheeting angle. Even with this modification, the clew was still too low to be properly sheeted. Thus, as a final modification, a triangular area was removed from the foot. This raised the clew by four feet and solved the problem. As in the case of the topsail, the comparison between the original and developed shapes can be seen by comparing Figures 1 and 3. Further trials with different sail configuration will be carried out in order to establish the relative advantages of each rig.

The original mast, made up of three bamboo poles, proved to be inadequately stiff. After various futile attempts to improve the staying of the mast, the mast itself was replaced by a solid wood spar, fitted in a substantial tabernacle in the local fashion.

This new mast, although only 11.4 cm thick at the base, was much stronger than the three 10.0 cm bamboos which it replaced. The bamboo topmast was excessively flexible and bent alarmingly under the combined load of the topsail and jib. Setting the topsail on a separate spar remedied the problem to some extent but did not totally eliminate it. A 1.9 cm nylon rope was first used for standing rigging because at the time, it was judged to offer the best strength and durability at reasonable cost. The nylon rope was later replaced by wire ropes because even with three shrouds per side, the rigging stretched excessively.

Despite the limitations and problems described, the boat demonstrated good sailing performance. During the trials, there were many opportunities to compare the trial boat with similar traditionally rigged boats. Before the wind, the speed of the new rig was very similar to that of the square sail, but in winds from abeam it was faster. With such beam winds, the leeboards were effective in reducing drift and yaw angle and made NOAMI-I more controllable than the traditionally rigged country boats. When winds are ahead of the beam, traditionally rigged country boats have to take down the sail and resort to manual propulsion, whereas NOAMI-I could continue sailing. Even when bearing directly against the wind, in force two or less, NOAMI-I could maintain a speed similar to boats under oar.

On some occasions between November to February, the wind became so weak and variable that the rudder failed to function. Even in such marginal conditions, the rig gave an encouraging performance. In other months, with more wind, the speed and general sailing ability was found to increase significantly. The boat was able to sail to windward faster than under oar or when being towed from the river bank. With the associated improvement in reaching performance, the average passage speed of the boat was significantly faster than that of traditionally rigged boats. It is worth mentioning that the tidal advantage has to be considered in making a sailing schedule. Sailing against the current is not possible in light wind conditions.

Project Achievements

Overall, the performance of the trial boat has achieved expectations and has demonstrated the potential for using improved sailing techniques on the country boats. In particular:

(i) Under sail power alone, the boat can proceed before, across and into the wind. Except in the narrowest waterways it can be navigated without use of human power;

(ii) Sailing speeds generally equal or exceed those of similarly loaded traditionally rigged boats when the wind is from astern. Across the wind, NOAMI-I is significantly faster. When sailing into the wind, it can still sail, whereas traditional boats have to resort to human power;

(iii) Being easily handled and maneuverable, the boat can make progress against the wind, even in narrow, crowded rivers. Generally it is better to take advantage of the tide in such conditions because frequent tacking could be hazardous;

(iv) A crew has been selected and trained in the application of the new techniques. New rig and gear can be managed by the same number of crew members as on the traditional boats;

(v) The new sailing techniques and equipment were quickly understood and applied by the crew;

(vi) A productive working relationship has been established between NOAMI-I members, the Consultants and the boat's crew;

(vii) The foundation has been laid for a significant improvement of the transport efficiency of the country boat fleet; and

(viii) All the changes embodied in the new design are within the capabilities of the traditional boat yards of the sector.

Economics of Modification

All the materials for rigging, sail and its fittings are locally available at low cost. The cost of sail material primarily determines the total cost of modification. If locally manufactured light canvas is used, the *bahari* type sail would cost around 7,000 taka (about US$210). Whereas, if ordinary coarse cloth is used, the sail would cost Tk2,300 (only about US$70). With such choices, the initial cost can be reduced to a third at the expense of durability and efficiency. Most of the fittings used in the experiment were the same as for those on traditional vessels. The size of sail will vary depending on the type of boat. Normally, the mast is a wooden or bamboo spar and the rigging is slightly inferior to that used on the trial vessel. Thus, the additional expense for sail, mast and rigging will not be more than about 10 per cent of what is usually spent for these items. For a new construction, the cost of modifications including sail, etc. will be around five to seven per cent of the total cost of the boat. Mechanization, on the other hand, needs a capital input of at least ten times for the cost of the engine, not including the extra cost for strengthening the hulls and other related prob-

lems. It has also been observed from the limited trials that the modified sail gives an average speed of 2.5 knots, as opposed to less than 1.5 knots by other country boats. Further trials on commercial routes are being undertaken for a comparative study.

EXTENSION PROGRAM

A new innovation needs proof of the experimentation, as well as explanation and demonstration to the users through appropriate means. NOAMI, with the assistance of UN-ESCAP, ITIS, and JAMDA, has been able to experiment and identify the largest possible group in our transport sector that would be the direct beneficiaries through a relatively very small capital input.

The country boats shape the pattern of daily life in our 68,000 villages. Unfortunately, the motive power of these boats is not commensurate to the human labor applied because of unsatisfactory sail and pulling arrangements. By introducing improved sail configuration, we are bringing about an improvement in the simple boat handling of our traditional water transport. Looking at the floating arrays of boats one could think that our people are still living in the era of Mohenjodaro, Harappa and Pharaoh's civilization. We are trying to accelerate the pace of development through the Project.

We have explained in this paper that the total cost of modification has to be within the means of the boat owner. We are therefore not proposing to change the country boat's hull configuration. Rather, we propose to adjust the sailing rig to fit the traditionally built boats. Since there are various types of country boats, a different size of sail has to be made for each different class. The basic principle of the sail will remain the same, only the shape of the rudder, the leeboards and the size of the sail have to be changed for each class.

CONCLUSIONS

The major conclusions noted in this paper are as follows:

(i) The transport system of Bangladesh is still in its early stage of development. Eighty per cent of the population is still dependent on traditional nonmechanized modes of transport;

(ii) The inland waterways transport sector (mechanized and nonmechanized) carries 51 per cent of all arterial freight traffic and 28 per cent of all passenger traffic;

(iii) In spite of large public and private input into mechanized transport, the nonmechanized sector is still responsible for carrying nearly 65 per cent of the total ton-km of inland waterways cargo and 55 per cent of the total passenger-km;

(iv) Out of the three major nonmechanized modes, the country boat is by far the largest, most dependable and least expensive; and

(v) The country boats can be made more efficient and faster by low cost, readily implemented improvements to the traditional sailing rigs.

The country boat sector deserves more developmental attention for the following reasons:

(i) Country boats account for 60 per cent of all employment and 33 per cent of all estimated payroll benefits of the transport sector;

(ii) Country boats have shown self-sufficiency in their operation and have developed over centuries to respond to the changing need for transport, without external assistance, and they are quite capable of adaptation;

(iii) With considerably less effort, the extensive waterways can be made navigable to country boats and provide access to almost any place in Bangladesh;

(iv) The labor-intensive nature of country boat operations can help erase the chronic problem of increasing unemployment; and

(v) The preliminary estimate suggests that the country boat sector is not only economically viable but is likely to prove superior to many mechanized modes if properly managed.

RECOMMENDATIONS

In view of the above conclusions, NOAMI therefore recommends that:

(i) The Government create a permanent cell within IWTA to look into the concerns of country boat operators. These concerns may include funding for the improvement of the sailing performance

of present fleet, experiments, procurement of wood of suitable quality and other construction materials for boat building, and provision of technical services and training programs for the boatmen. Similar organizations to NOAMI can cooperate with the Government in this respect;

(ii) Another second-hand boat similar to NOAMI-I be hired to measure the relative performance of the sprit and gunter sailing rigs;

(iii) The economics of modification in terms of increased capital cost and potential for increased revenue-earning capacity be further evaluated; and

(iv) Demonstrations and training programs be arranged to show the advantage of the NOAMI-I Project rig for adoption by existing country boats.

It can be seen that we have to work simultaneously in two directions. We should make our boat people understand that the changes demonstrated by the NOAMI-I project can be brought about without too much expense, with the benefit of faster voyages and without a decrease in the size of the crew. We must also continue with the experiment for adoption in all other classes of countryboats. Such a project will benefit our country and needs to be supported by all agencies. The Bank may consider sponsoring, through NOAMI, further work to attain the foregoing objectives.

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QUESTIONS AND ANSWERS

Q: The hardest job is usually to convince people to adapt to sudden change. Could you comment on the view that if benefits are spelled out in terms of real taka, the boat people may be more willing? (Mr. A.B. Thakur)

A: Absolutely. Improving the turnaround will improve the boat people's income, then perhaps, change will be effected.

Q: Could you elaborate on the impact of the project on the finely balanced infrastructure of the country boats system? If any change is made, would this not change the social structure, considering that this may reduce the number of boats? (Mr. R.G. MacAlister)

A: The present construction of boats is generally decreasing because of the nonavailability of appropriate wood and construction materials. The project will indeed result in a decrease in the number of boats but not enough to disturb the social fabric. The number of boats will decrease over a period of time, particularly the passenger boats.

Q: What is being done to improve the traditional boat building sector? (Mr. L.P. Dassanayake)

A: Different types of boats are being produced but an integrated program of construction with the help of soft loans is needed.

Q: Are there any legal requirements that the country boats have to fulfill regarding the safety of cargo and people? (Mr. W. Mapuru)

A: There are no legal requirements; these boats are not even registered.

Q: I would like to know more about the rudder which can cause a few problems. Would the use of a quarter rudder, which is more traditional, improve performance? (Mr. P. Schenzle)

A: Because the water is generally shallow, one can just jump over the side and fix the rudder. I agree, however, that this matter requires proper examination.

Applications of Windship Technology in the Design and Operation of Wind-Propelled Ships*

Christopher J. Satchwell

INTRODUCTION

In 1982 and 1983, Dr. J. H. Mays and the author developed a linearized theory for the analysis of sailing and motor-sailing (Satchwell and Mays, 1983). That theory has been applied to transatlantic voyages of SD 14 cargo vessels, the Fijian wind-assisted ship *Na Mata-I-Sau* and a number of other windship design studies. In the course of this work, various practical problems that occurred during procurement and operation of wind-propelled ships were identified. Linear windship theory has been adapted to solve these problems and could be further adapted to solve many others in windship development. The purpose of the present paper is to describe some of the practical difficulties that have been solved by the application of linear windship theory to demonstrate its application in providing answers to design, procurement and operational questions.

Various proposals in response to specified requirements can usually be formulated satisfactorily. Each proposal should then be tested for its suitability to the intended operation. This testing would be in terms of the performance offered and its impact on other aspects of the ship operations. Assessment of such performance will usually involve both operational and financial considerations and may include such matters as cargo handling or bridge clearance as well as the broader requirements of routes, traffic and voyage frequency, etc. Various sail rig types may show optimal performance on particular routes; thus at this stage of a procurement analysis, it may be

* The preparation of this paper spanned both Wolfson-funded and SERC-funded wind energy projects, and grateful acknowledgements of support are made to both organizations. Thanks are due to Dr. A. F. Moll and for his assistance on questions of engine/propeller performance under partial load. Thanks are also due for the support of all staff of the Department of Ship Science, Southampton University.

appropriate to formulate separate proposals for each rig type involving a mix of wind-propelled and engine-propelled vessels. At some stage, an optimal ship speed should be chosen, after the commercial implications of ship speed variations have been evaluated.

At the end of this exercise, the operator should: (i) have decided how to use each rig type optimally; (ii) have understood related operational matters; and (iii) know the commercial facts to enable him to make a procurement decision. Strategic decisions regarding routes for wind-propelled ships can also be made at this point, although these may be subject to tactical variations to take advantage of favorable winds. A flow diagram of the procurement/design process is shown in Figure 1.

LINEAR WINDSHIP THEORY

Linear windship theory was initially developed around the following limited set of assumptions:

(i) A marine airfoil would be very tall in relation to the superstructure; and

(ii) The hull would have a deep keel fitted to it.

These two assumptions enabled a marine airfoil (rig) to be treated as a wing protruding from the sea into the air, and the keel, as a wing protruding from the air into the sea. Regardless of the way in which the dimensions of these 'wings' were obtained in the theory, the performance of many real rig/hull/keel combinations can be described in terms of the formulae of linear windship theory, with the following limitations:

(i) The dimensions of 'wings' representing the rig and keel come from experimental results; and

(ii) There may be limited intervals in which the formulae apply, and different constants may be required for different intervals.

The most efficient hull/keel combinations and marine airfoils will generally obey the formulae of linear windship theory, but less efficient hull/keel relationships or marine airfoils, are often specified for reasons of operational requirements, tradition, or arbitrary design. At present, linear windship theory can be criticized for being unrepresentative of existing rig/hull combinations, but there is likely to be pressure to raise the efficiency of rig/hull combinations to the point where they will be well

Figure 1

Overview of Windship Design

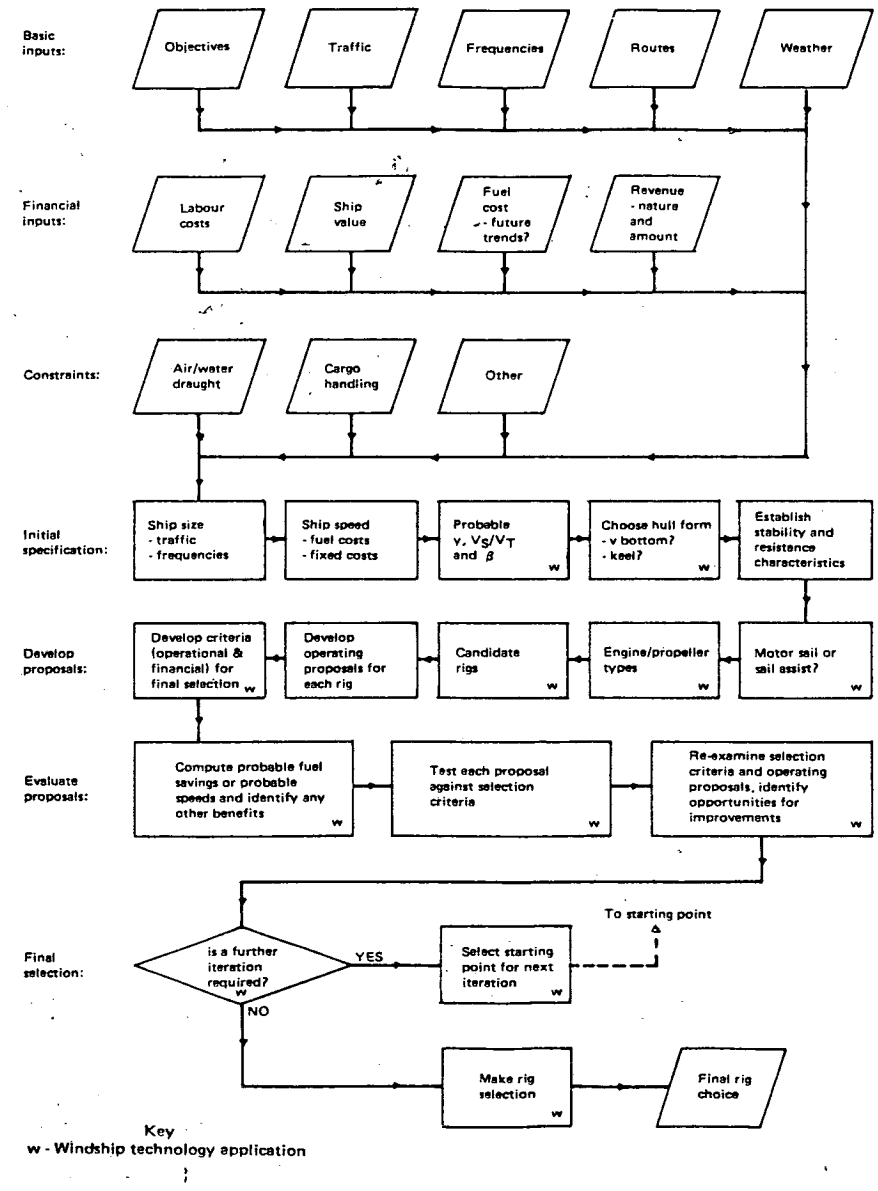
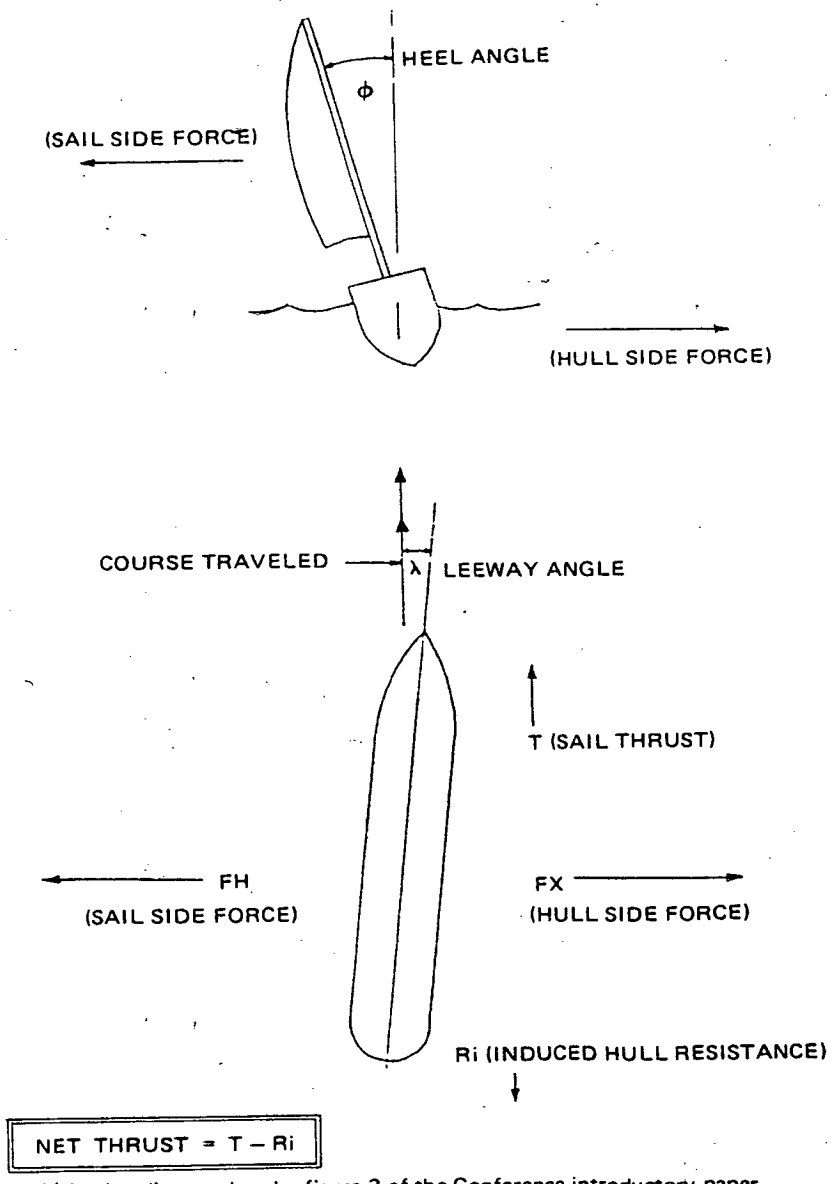


Figure 3

Sail-Hull Interaction 1/



1/ As also discussed under figure 3 of the Conference introductory paper, An Overview of Wind Assisted Propulsion for Commercial Shipping.

represented by linear theory formulae. Applications of the theory will then be more simple than at present.

Linear windship theory uses two nondimensional coefficients, C_{ER} and C_{EP}. Both are measures of the net propulsive effect of a rig/hull/keel combination, nondimensionalized with respect to air density (ρ_a) rig equivalent area (Ser) and true windspeed (V_T). Net thrust from the sail is shown on Figure 2 to be $T\text{-}R_i$.

$$C_{ER} = (T\text{-}R_i)\ (\tfrac{1}{2}\rho a\ V_T^2\ Ser) \quad = \text{effective drive coefficient}$$

$$C_{EP} = (T\text{-}R_i)\ .\ V_s\ (\tfrac{1}{2}\rho a V_T^3\ Ser) = \text{effective power coefficient}$$

The formulae for C_{ER} and C_{EP} may be obtained from the aerodynamic theory for a limited range of rig/hull/keel combinations, and are typically of the form:

$$C_{EP} = a\sqrt{a^2 + 1 + 2a\cos\gamma}\ .\ (C_{Lr}\sin\gamma - [C_{Dor} + k_r C_{Lr}^2/\pi AR_r][a + \cos\gamma])$$

$$\frac{(a^2 + 1 + 2a\cos\gamma)(C_{Lr}[a + \cos\gamma] + [C_{Dor} + k_r C_{Lr}^2/\pi AR_r]\sin\gamma)^2 \rho_a S_{er}}{\pi(\eta T)^2 \rho_s . a}$$

$$C_{ER} = C_{EP}/a$$

Derivations are given in Satchwell, 1983, 1985[a] and 1985[b].

Results of wind tunnel tests, towing tank tests, and sail trials can be used to provide an indication of the constants and variables in the formulae for C_{ER}. Unfortunately, getting these results is expensive. The normal practice, therefore, is to combine the aerodynamic theory with whatever results have been published. Where only one aspect of a problem is seriously in

doubt, linear theory may be used to work backward from the trial results to shed some light on that aspect. This was done for the ADB *Na Mata-I-Sau,* experiment in Fiji for which details of induced resistance were deduced from towing tests, sail trials and estimated sail performance.

The general position is that some test work will be needed to provide a good estimate of the net propulsive effect of a rig. However, less accurate estimates can be obtained from a background of published data.

When the propulsive effect of a rig is established for arbitrary use, there is a problem of how to use it optimally, particularly under sail-motor. This problem, too, may be solved by linear theory, through the use of a method shown in Satchwell, 1985[a]. The method involves differentiating C_{EP} with respect to C_{Lr}, equating to zero, solving a cubic for an optimal C_{Lr} and then obtaining a rig setting angle from a graph of C_{Lr} vs incidence.

If optimal C_{Lr} values are obtained for all ship speed/true windspeed ratios (a) and true wind angles (γ), then a surface of $C_{EP}(a, \gamma)$ can be obtained. This surface is a measure of the wind power obtainable from an optimally used rig/hull/keel combination.

Where a ship is to be propelled solely by the wind, linear theory suggests that at low speeds, the ship's performance may be described by a single plot of $a\ v \cdot \gamma$ i.e. $a = a(\gamma)$. Sail trial results for *Na Mata-I-Sau* support this conclusion.

The remaining part of the problem is to predict either fuel savings or an expected ship speed. Such predictions can be made, on the basis of historical weather data and are strictly either probable fuel savings or a probable ship speed. Probable quantities are, for example, a commodity of the insurance industry, where they form the basis of most financial decisions. In the present case of wind-propelled ships, it is reasonable to assume that over a long period, performance may be predicted using historical weather records, which enable probable fuel savings and ship speeds to be used as a basis both for evaluating design changes and for appraising investments. Formulae for predicting fuel savings or ship speed involve a probability density function for the weather pdf (Θ, V_T), a course (Θ_1), and the true wind angle ($\gamma = \min\ |\Theta - \Theta_1|\ ,\ 2\pi - |\Theta - \Theta_1|$)

(See Satchwell, 1985[a]).

$$V_{ps} = \int_0^{\infty} \int_0^{2\pi} V_T \cdot a(\gamma)\, pdf(\gamma, V_T)\, d\gamma\, dV_T$$

$$F_p = \frac{\int_0^{D} \int_0^{\infty} \int_0^{2\pi} pdf(\gamma, V_T) \cdot C_{EP}(a, \gamma) \cdot \tfrac{1}{2} \rho_a V_T^3 \cdot S_{er} \cdot SFC \cdot d\gamma \cdot dV_T \cdot dD}{V_s \eta_D \eta_T}$$

The formula for F_p contains a propulsive efficiency term D_r as well as specific fuel consumption, SFC.

The usual method of evaluating F_p involves a constant SFC, chosen to be appropriate to a normal power setting for the engine. In doing this, there are implicit assumptions that any energy provided by the wind does not have to be provided by the engine, and that the engine/propeller will be as efficient under part load as under normal load. How well these assumptions reflect the performance of a particular engine/propeller installation needs to be reviewed case by case. In general, engines perform less efficiently under part load than under normal load, but most propellers can show a significant increase in efficiency under part load.

Two examples have been distilled from Molland and Hawkesley, 1985, with one author's assistance and the use of unpublished background calculations. One measure of the engine/propeller performance under part load is the quantity SFC/($\eta_D \eta_r$), which is a specific fuel consumption based on effective power provided. Good engine/propeller performance is indicated when this is low.

Example 1: Coaster, 11 knots (constant speed), powered by a four stroke medium-speed diesel engine:

Thrust (% of normal)	RPM	$\eta_D \eta_r$	SFC %	SFC/($\eta_D \eta_r$) %	Ratio of SFC/($\eta_D \eta_r$) (for part load/ normal load)
100	163.3	.670	99	148	1
75	148.9	.712	100	140	.946
50	132.4	.762	103.5	136	.919
25	113.0	.793	112	141	.953

Example 2: Cargo vessel, 14 knots (constant speed, powered by a two stroke low-speed diesel engine):

Thrust (% of normal)	RPM		SFC %	SFC/($\eta_D \eta_r$) %	Ratio of SFC/($\eta_D \eta_r$) (for part load/ normal load)
100	112	.671	100	149	1
75	102.7	.710	99	139	.933
50	91.9	.754	100.5	133	.893
25	79.2	.772	104	135	.906

These illustrative examples show that the engine/propeller combination commonly works up to 10 per cent more efficiently under part load than under normal load. Use of wind assistance generates additional fuel savings by providing a more efficient operating environment for the propeller.

It would be unwise to generalize this conclusion since propeller efficiency fails rapidly once the optimum is passed. The implication of this trend is that some examples must be expected where the engine/propeller performs less efficiently under part load than normal load. The central point, however, is that the use of normal load values of SFC, η_D and η_r, to calculate probable fuel savings (F_p) is a realistic assumption in the absence of any obvious reason to the contrary. These results for engine/propeller efficiency under part load are summarized in Figure 3.

A flow chart to indicate the procedures employed with the linear windship theory is shown in Figure 4, in the context of an initial windship design calculation.

WINDSHIP TECHNOLOGY APPLICATIONS

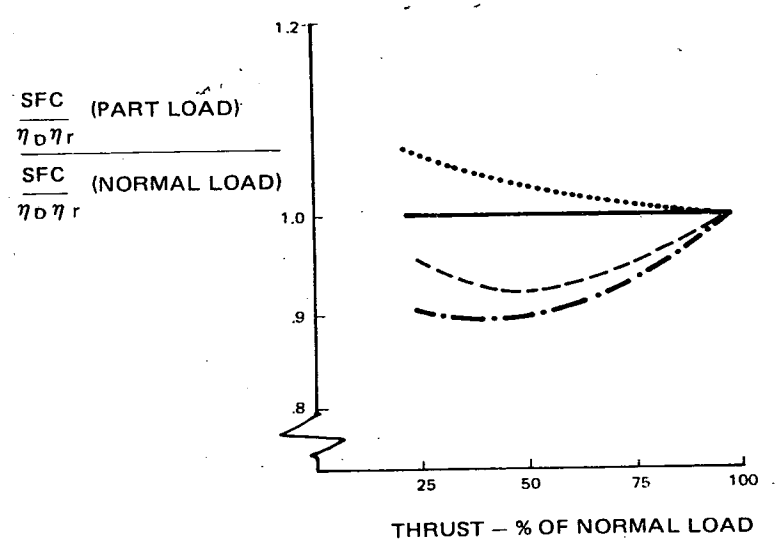
Windship technology may be applied at various stages during the procurement and operation of a vessel.

Candidate Rig Types

An initial examination of a procurement problem should indicate predominant values of γ and 'a', from which candidate rig types may be assessed for their suitability. Each rig type will be associated with some parasite drag coefficients (CDo) and some induced drag factor (k), and the naval architect will have to formulate a proposal for appropriate rig dimensions for that particular hull. If the objective is to obtain speed under wind power, then graphs involving principal dimensions and the product of C_{EP}.Ser provides a measure of the ship speed/rig dimension trade-off. In a similar way, graphs involving rig dimensions and the product of C_{EP}.Ser provides a measure of the fuel/rig dimensions trade-off. These are essentially approximate methods to obtain an initial design. More exact plots involving rig dimensions and the quantities V_{ps} and F_p can also be obtained, but they require much more computational effort. These initial procedures are summarized in Figure 4 and provide an approximate method for evaluating design changes. An illustrative example of this technique is provided in Annex I for a problem involving rig height optimization.

Figure 3

Engine/Propeller Efficiency Under Wind Assistance

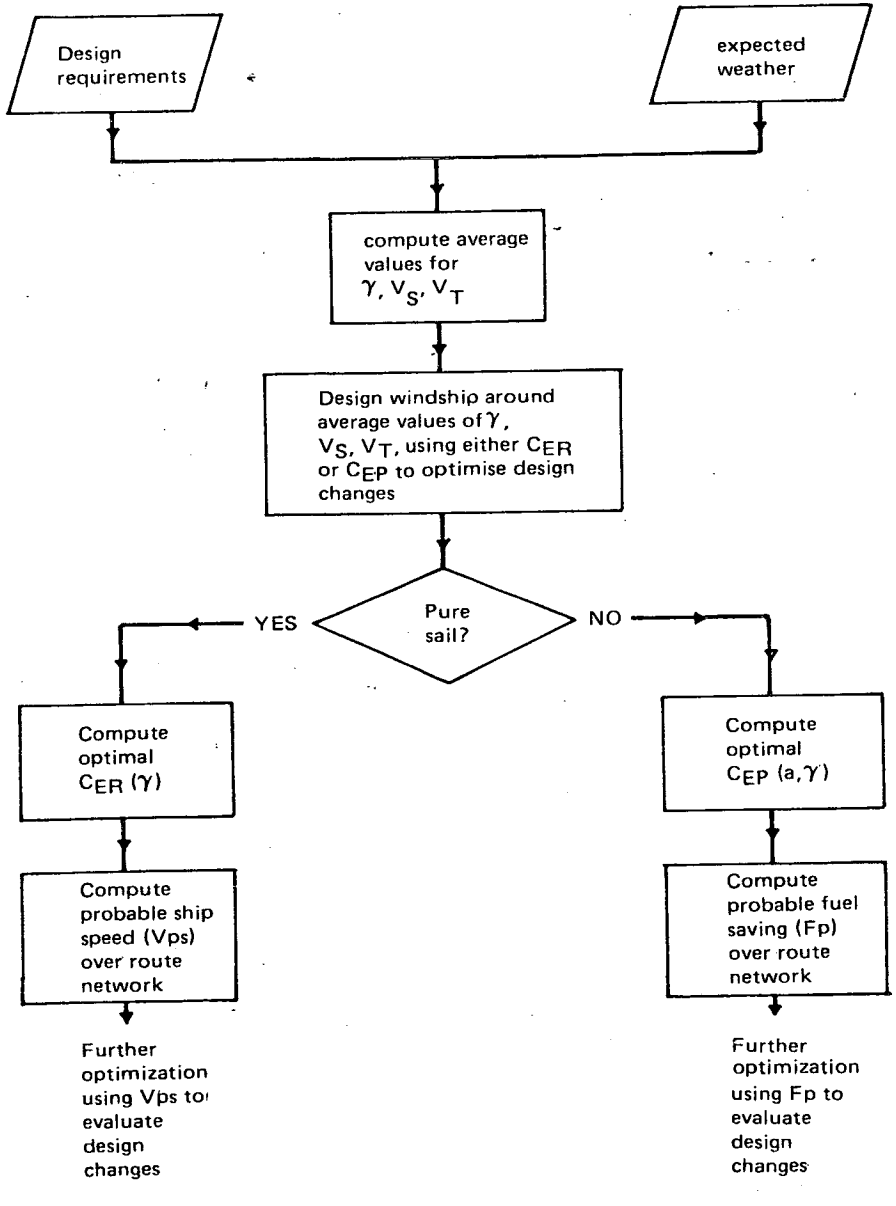


KEY:

- ..... Intuitive Expectation
- ——— Assumption in Linear Windship Theory
- - - - - 11 Knot Coaster, 4 Stroke Medium Size Diesel Engine
- —·— 14 Knot General Cargo, 2 Stroke Slow Speed Diesel Engine

Figure 4

Procedure for Initial Windship Design Calculations



Routing

In planning a wind-propelled ship operation, it is important to identify a variation of probable fuel savings with course, or expected ship speed with courses. This enables the wind-propelled ship operation to be planned for optimal courses. The relative fuel savings for various courses can be worked out for a range of representative speeds. Relative fuel savings require a datum which is taken as the average fuel saving for a voyage in a random direction. The relative fuel saving is then the fuel saving in a particular direction, divided by the average fuel saving for a voyage in a random direction. A good course is indicated where the relative fuel saving exceeds 1.0. Figure 5 shows plots of relative fuel savings versus course, for three ship speeds.

An illustration of the use of Figure 5 is given in Annex II, where optimal routing for a triangular network is considered.

There are additional ways of presenting wind propulsive versus course information that can help further in answering strategic routing questions.

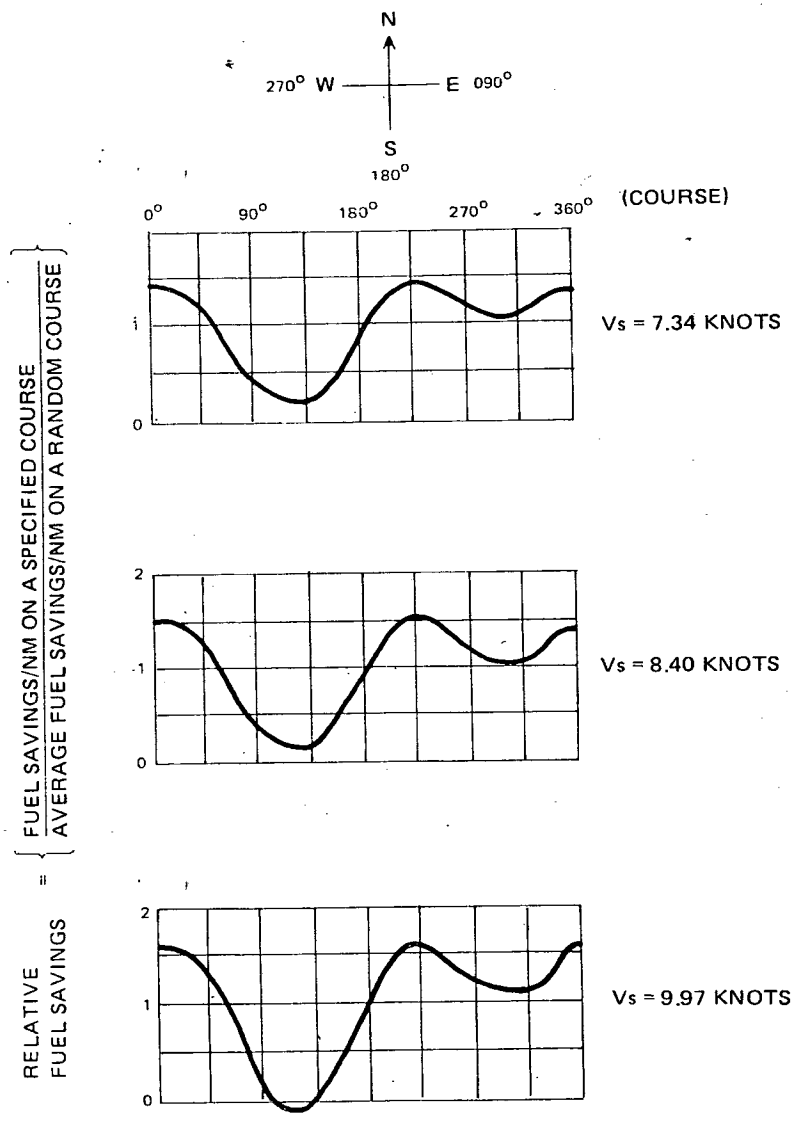
Fuel Savings on a Route Network

Formulae for probable fuel savings F_p and probable ship speed V_{ps} have been given for individual sectors. When a combination of sectors (i) and sector frequencies (n_i) are present, then the fuel savings for a sector (Fp_i) need to be appropriate to sector frequency, that is, $\eta_i \cdot F_{pi}$. For the whole network, the fuel savings are $\Sigma i \ \eta \ i \ . \ Fpi$. When the fuel savings for the whole network are computed, the impact of wind assistance can be expressed in a variety of ways. One way that is usually intelligible involves a fuel consumption versus ship speed graph. To produce this graph, one has to know about hull resistance and engine and propeller characteristics, which will all change with time and sea conditions. If certain limitations are imposed, such as calm water, a well-maintained engine, etc., then fuel consumption versus speed graphs can be produced. Figure 6 is one example. Figure 6 shows that reducing ship speed is a powerful way of saving fuel, but ignores possible changes in engine/propeller efficiency. Calculations for this paper suggest that for existing ships, speeds should not be reduced too far below their design values and that wind propulsion may have a favorable effect on propeller efficiency. With a new vessel, it should be possible to design a wind/engine propulsion system to realize the fuel-saving potential of slow ship speeds, as suggested in Figure 6.

Once a graph such as Figure 6 is computed, it becomes possible to work out a rate of return or any other investment appraisal criterion required for procurement.

Figure 5

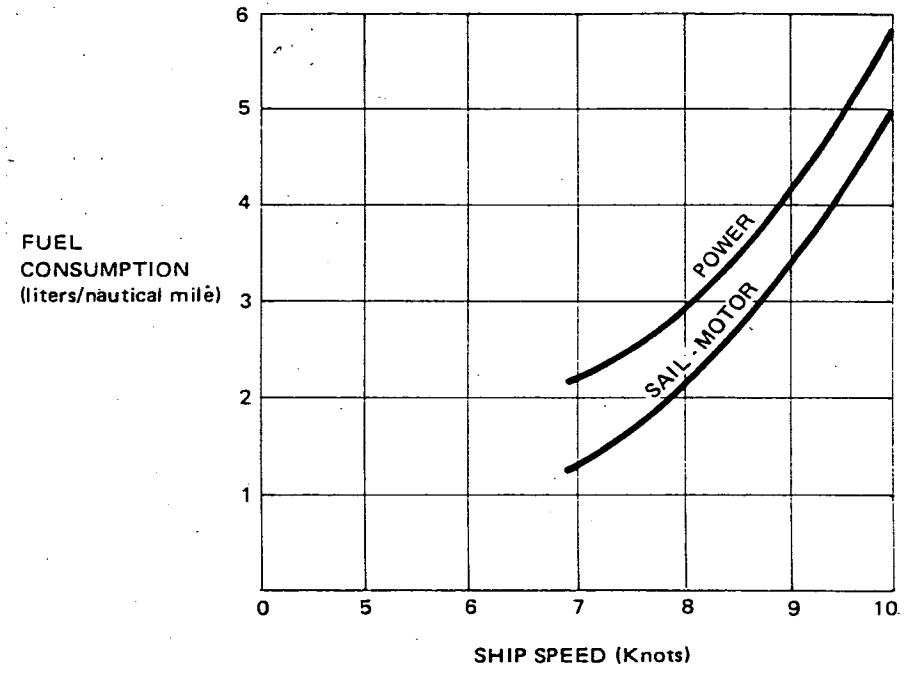
Sample Graphs of Relative Fuel Savings vs Course 1/



1/ As also discussed under Figure 3 of the Conference Paper by Mr. R.G. MacAlister, The Retrofitting of Sail to Two Existing Motor Ships of the Fiji Government Fleet.

Figure 6

Sample Graph of Fuel Consumption vs Speed for a Small, Wind-Assisted Ship, Operated Near Fiji 1/



1/ As also discussed under Figure 2 of the Conference Paper by Mr. R.G. MacAlister, The Retrofitting of Sail to Two Existing Motor Ships of the Fiji Government Fleet.

Some cautionary note needs to be made about Figure 6. If a ship operates in waves or strong headwinds, then resistance increases and the two curves of Figure 6 both move up the y (liters/nautical mile) axis. A similar effect happens when engine efficiency declines or weed growth occurs on a hull. There is no accurate way of predicting fuel use in arbitrary conditions, only in certain specified conditions. However, the absolute fuel saving from wind propulsion is unlikely to be reduced in the event of waves, weed growth, etc., and may very well increase because of ship motion improvements.

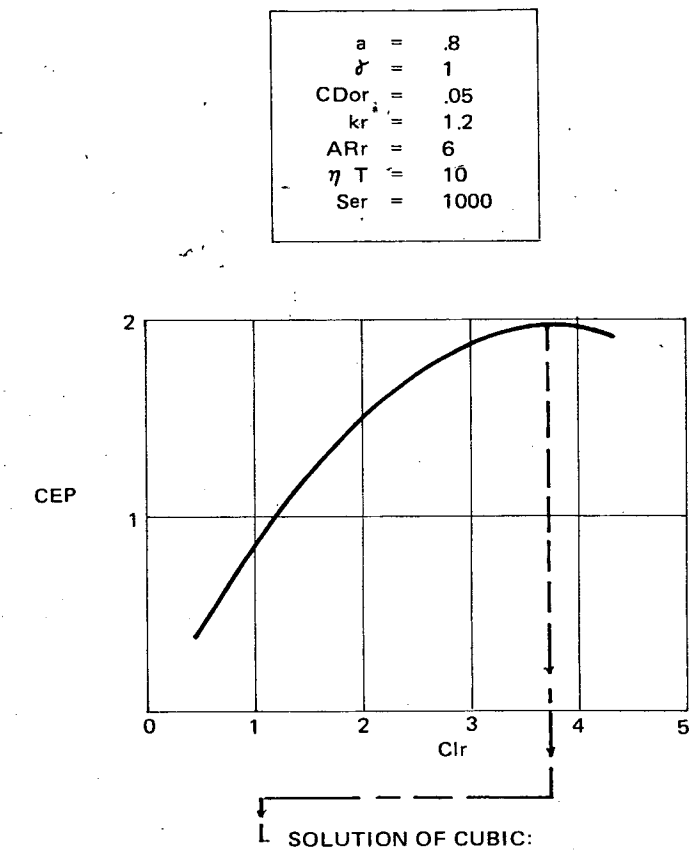
Optimal Rig Use

In computing F_p or V_{ps}, some assumptions have to be made regarding rig use. Linear windship theory has been applied to this problem, and an indication obtained for optimal use. A first approximation of an optimal rig lift coefficient (C_{Lr}) for maximizing fuel savings is given by the condition that C_{EP} is a maximum. This may be found by plotting C_{EP} against C_{Lr} for specific values of 'a' and 'γ', and observing the maximum. Alternatively, C_{EP} may be differentiated with respect to C_{Lr}, equated to zero and the resulting cubic solved for C_{Lr}. Figure 7 shows the results from both approaches, both yielding the same answer. When C_{Lr} is obtained, apparent wind direction (β) is computed and an incidence (α) obtained from a graph of C_{Lr} v. α. The rig can then be set at this incidence, corresponding to an angle to the vessel's center line of $\beta - \lambda - \alpha$. For automatically controlled rigs, it should be possible to approach an optimal value of C most of the time. With manually controlled rigs, such precise control is rarely obtained, and there is usually some doubt as to how well a crew will perform and how this will influence F_p and V_{ps}. These calculations may be repeated for every possible configuration of 'γ' and 'a' values, to obtain recommendations for both optimal configuration and setting angle for a specified rig and ship. Similar recommendations may be obtained for a vessel under wind power alone, by finding a maximum of C_{ER} with respect to C_{Lr}, for each value of γ, with a(γ) appropriate to the vessel's pure sail performance. This process provides a guide to optimal rig use and enables an operator to extract maximum benefits from his wind-propulsion device, particularly with an automatic control system.

Figure 7 also provides a guide to the sensitivity required of the control system. An optimum value of C_{EP} occurs at a C_{Lr} value of 3.75. However, if C_{Lr} is varied within the range 3.0 to 4.6, the value of C_{EP} is always within five per cent of the optimum. The example of Figure 7 was worked out for a hybrid flapped multiplane, where the C_{Lr} range of 3.0 to 4.6 corresponds

Figure 7

Variation of C_{EP} with C_{LR}



$$C_{Lr}^3 + \frac{3}{2}\frac{\psi}{\Omega} C_{Lr}^2 + \left[\frac{\psi}{\phi\Omega\sin\gamma} + \frac{\psi^2}{2\Omega^2} + \frac{C_{Dor}\sin\gamma}{\Omega}\right] C_{Lr} + \frac{\sin\gamma}{2\Omega^2}\left[C_{Dor}\cdot\psi - \frac{1}{\phi}\right] = 0$$

$$\text{where } \psi = a+\cos\gamma \;;\; \phi = \frac{2\rho_a S_{er}}{\pi(nT)^2\rho_s a^2}\sqrt{a^2+1+2a\cos\gamma} \;;\; \Omega = \frac{k_r\sin\gamma}{\pi AR}$$

to about a ten-degree incidence range. This implies that a fairly inaccurate control system will suffice.

CONCLUSIONS

This paper has sought to illustrate some applications of windship technology in optimizing rig design and operation. The theory has been described as a means of combining rig, hull and weather information to achieve either probable fuel savings or a probable speed under wind power alone. Crucial assumptions on both fluid mechanics and engine performance have been examined and some limitations identified. A calculation of probable fuel savings or voyage speed has been shown to involve a process of initial design, optimization of rig use, and probable performance evaluation on passage.

A design procedure for good procurement is shown in Figure 1, with windship technology applications indicated. A summary of principal applications is discussed, and relevant examples are provided in Annexes I and II.

One of the main problems encountered by wind-propelled ship designers involves assessing the value of a design change. In the present field, value can often be expressed in terms of a change in fuel savings or speed. Windship technology provides one tool to place a figure on value and enables the designer to make rational decisions, as shown in the example of Annex I.

Windship technology also provides an aid for the strategic planning of wind-propelled ship operations. An example in Annex II shows how a vessel is optimally routed to achieve both additional fuel savings and ship motion improvements.

After design and routing questions have been resolved, a windship operation can be analyzed to produce fuel consumption versus speed graphs such as Figure 6, both with and without wind propulsion. Such graphs have limitations; nevertheless, they provide a rational basis for strategic decisions on investment in wind assistance and subsequent operational ship speeds.

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3. Satchwell, C. J., "The Evaluation of Wind Power for Commercial Vessels," The Naval Architect, 1985[a].

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ANNEX I

ILLUSTRATIVE EXAMPLE OF RIG HEIGHT OPTIMIZATION

Using the clockwise routing and other dimensions from Annex 1, the wind energy provided by rigs of constant chord but of varying height can also be examined. Weather data and ship details are appropriate to 180 degrees east longitude and 10 degrees south latitude for a 27 meter length vessel travelling at 8.4 knots. There is a stability limit when the rig height reaches 18 meters.

Apply the formula for F_p on the three sectors, for a range of rig heights. Energy savings from wind power (kWh of EP)

Rig

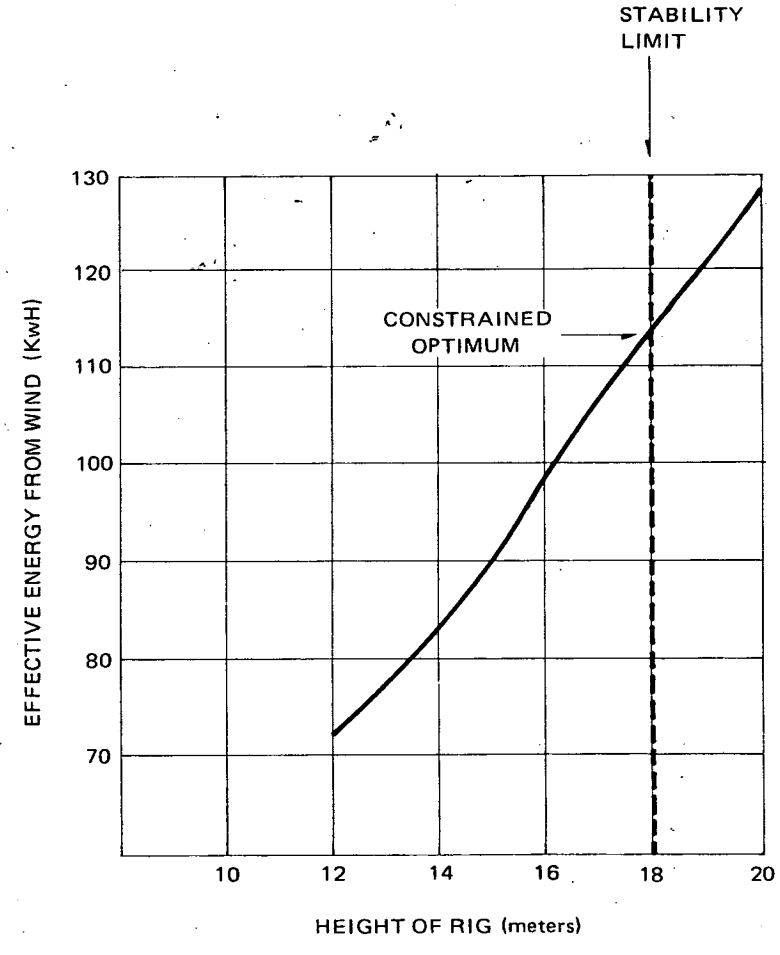
Height:	12m	14m	16m	18m	20m
Sector					
AB	19.26	23.29	28.29	33.00	37.79
BC	19.45	20.68	23.45	26.15	28.83
CA	33.81	39.52	46.87	54.05	61.27
Totals	72.52	83.49	98.61	113.20	127.89
Fuel Savings (kg)	34.81	40.08	47.33	54.34	61.38

These results are plotted at Figure I, Annex I.

Application of linear theory to this example shows that increasing the height of the rig tends to increase fuel savings proportionately. The rig height should therefore be increased to the stability limit. Probable rig costs might involve a constant element and an element proportional to area. If rig costs approximate this trend, then the taller rig is more cost-effective. When rig costs and fuel costs are available, the variation of the rate of return or some other appraisal criterion with rig height may then be examined and on this basis a different optimum might be indicated.

Figure I

Illustrative Example of Rig Height Optimization



ANNEX II

ILLUSTRATIVE EXAMPLE OF A ROUTING APPLICATION USING FIGURE 5

A vessel can travel a triangular route clockwise or anticlockwise. A graph of relative fuel savings versus course (Figure 5 for V_S = 8.4 knots) can be used to find the routing that gives maximum fuel savings. Note that fuel savings is proportional to the product of relative fuel savings and distance.

Sector	Distance (km)	Course (degrees to north)	Relative Fuel Saving (Figure 5)	Relative Fuel Saving x distance (km)
AC	50	217	1.42	71
CB	30	090	.35	10.5
BA	40	000	1.47	58.8
Sub-total for anticlockwise routing				140.3
AB	40	180	1.02	40.8
BC	30	270	1.35	40.5
CA	50	037	1.35	66.5
Sub-total for clockwise routing				147.8

This example shows that clockwise routing produces greater fuel savings. The ratio of fuel savings for clockwise/anticlockwise routings is 147.8/140.3 or 1.05/1. Another conclusion can be drawn from this example. The anticlockwise routing shows high and very low relative fuel-savings figures. High relative fuel savings suggest an excess of wind propulsion when the wind blows hard, which could result in high values of Vs/L and high ship resistance. Low relative fuel savings suggest the vessel is going either directly upwind or downwind and that aerodynamic damping may not be present. On triangular courses it is probably better to avoid high or low relative fuel savings and aim at keeping the sails working moderately well all the time. An examination of fuel saving figures for the clockwise routing suggests that the sails were working moderately well all the time and the ship's motion was better damped than with anticlockwise routing.

ANNEX III

SYMBOLS USED IN THE PAPER

Name	Meaning
V_S	Ship speed
V_T	True Wind speed
V_A	Apparent wind speed
a	V_S/V_T nondimensional ship speed
γ	True wind angle
β	Apparent wind angle
λ	Leeway angle
η^T	Fractional draught, used for calculating Ri
T	Sail thrust
R	Induced resistance
C_{Lr}	Rig lift coefficient
C_{Dr}	Rig drag coefficient
ρ_a	Air density
ρ_s	Sea density
Ser	Equivalent rig area
C_{ER}	Nondimensional drive coefficient for rig/hull
C_{EP}	Nondimensional power coefficient for rig/hull
O	Angle of true wind from northerly direction
Vps	Probable ship speed under wind power
F_p	Probable fuel saving from wind power
D	Distance along rack
η_D	Quasi-propulsive efficiency
η_r	Transmission efficiency
SFC	Engine specific fuel consumption
pdf(Θ, V_T)	Probability density function for wind speed and direction
RPM	Revolutions per minute
k_r	Induced drag factor for rig
k_k	Induced drag factor for keel

The Application of Sail in Fisheries Development

R. Gowan MacAlister

INTRODUCTION

Of the world annual fish catch of some 70 million tons, 40 per cent is landed by small-scale and artisanal fishermen. Between 20 and 30 million developing world fishermen, their families, traders and distributors, depend on these fisheries for their livelihood. Because of the geographical dispersion of these fishing activities, fish distribution is widespread. In many countries, fish is the main source of animal protein in the diet.

Traditional fishing craft vary greatly in design but not in concept. They are manufactured from locally available materials and develop within the constraints of those materials. Until recent times, propulsion has been by paddle or sail, generally with high levels of competence. Many small-scale fishing craft are beach-based, launched and recovered by their crews. Since the 1950s, mechanization has been introduced almost universally and many changes have been seen in small-scale fisheries. Mechanization has resulted in improvements in productivity by increasing available fishing days, opening up new fishing grounds and introducing more efficient fish catching methods.

Many canoe type small boats have benefited from outboard motors and larger traditional craft have been fitted with diesel engines. In the era of abundant cheap fuel, mechanization resulted in increased supplies of fish for human consumption at prices affordable by rural populations.

Rapid increases in fuel prices in the 1970s threatened the economic viability of small-scale mechanized fishing vessels which are still operated on patterns established during the era of cheap fuel.[1]

1 Since presentation of this paper there has been a rapid, and most people believe temporary decline in the price of fuel. However, for the artisanal fishermen of Yelibuya in Sierra Leone, gasoline prices are still as high as $3.08 per liter and show no indication of fully reflecting the reduced prices paid to the oil producers. This is a pattern which is repeated in many areas of the world. (Additional advice provided by the author in July 1986.)

EFFECT OF RISING FUEL COSTS ON SMALL MECHANIZED FISHING CRAFT

Two major effects on the viability of artisanal fisheries have resulted from fuel cost increases. The first and most obvious is the direct rise in operational costs. At the same time, the general recession caused by fuel cost increases has decreased the purchasing power of consumers in developing countries. This has put pressure on primary producers such as farmers and fishermen, not permitting the prices of primary products (including fish) to rise at a rate that will permit the increased operational costs to be passed on.

Secondly, the greatly increased foreign exchange requirement for the purchase of fuel oil and the higher prices charged for imported manufactured goods have caused such an imbalance in the external trade of many developing countries that they have difficulty in obtaining sufficient foreign exchange for importing even the most essential amounts of fuel oil and mechanical equipment. All of us are familiar with fuel cost increases in our own countries which affect us directly. For example, diesel cost about rupiah 40 per liter in Indonesia in 1980 while in 1985, the cost is about rupiah 180 per liter. However, in many developing countries, even higher price rises have occurred and for the reasons given above, price increases cannot be passed on to the consumer. Therefore, fishermen have been forced to absorb the increased operating costs which over the period has reduced profitability, incentive and activity.

Some examples from sail project experience indicate the gravity of the situation:

(i) To small-scale fishermen in Indonesia, fuel prices increased by 450 per cent from January 1980 to January 1985. Market forces have held the price of fish to within 30 per cent of the 1979 level. There are many restrictions on industrial fishing operations to conserve fish stocks and encourage small-scale fisheries, but with present motorization in certain parts of Indonesia, small-scale fishery is uneconomic.

(ii) In Somalia, with per capita earnings of US$180, gasoline is only available with a government permit for every liter bought at the pumps. Diesel is more easily obtainable at equivalent US$0.50 per liter (1982) but is of poor quality with many impurities. Engine spare parts for small engines have been unobtainable for some years, except when supplied by aid organizations.

(iii) In Guinea Bissau, where per capita earnings are US$160 per year, fuel is seldom available. Periods of two or three months without supplies for the fishermen are not uncommon. The price of gasoline is equivalent to US$0.78 per liter and diesel US$0.38 per liter.

(iv) In Sierra Leone, fuel is generally in short supply. In recent months, the supply situation has deteriorated further and artisanal fishing activity has been severely reduced. Petrol prices of an equivalent US$0.60 per liter already represent 70 per cent of operating costs. This should be compared with the 1978 per capita earning of US$182.

(v) In Senegal, with per capita earnings of US$223, the small-scale beach fishery is very highly developed and supplies large quantities of fish to the rural population via a well organized artisanal distribution system. There are approximately 3,000 canoes operating on the coast, using modern fishing methods to meet ever-increasing demands. Almost all canoes are powered with an outboard motor. The Government has subsidized small-scale fishery by allowing fishermen to purchase fuel and outboard motors without the 60 per cent tax paid by all other users. Even with this advantage, diesel fuel costs of US$0.27 per liter represent 40 per cent of operating costs. Without the subsidy, operation of the motorized canoe fishery would not be viable.

(vi) The subsistence fishery in Madagascar continues to supply small quantities of fish to coastal villages using traditional sail powered outrigger canoes. Attempts to develop an artisanal fishery have been unsuccessful as operating costs of engines make the activity uneconomic.

At the present rate of decline, many artisanal and small-scale fisheries, which are already commercially marginal, will severely reduce catching effort. Inevitably, the locations affected first are those with the most pressing need for improved diet. These areas are in danger of losing a large proportion of fish catch and a valuable source of protein.

SOME SOLUTIONS TO THE PROBLEM

The task of reducing fuel costs in small-scale fisheries must be tackled on many fronts. This paper is primarily concerned with the use of sail power as a means of reducing fuel consumption and thus operating costs. However, other avenues must also be pursued. Fyson, 1982, lists five options which could be used singly, or in combination:

(i) Develop improved energy efficient engines and/or propelling devices;

(ii) Concentrate on reduction of hull resistance in the design of new fishing vessels;

(iii) Change fishing emphasis from high energy consuming fishing methods to those requiring lower energy inputs as, for example, switching from stern-trawling to mechanized long line systems for high quality bottom fish stocks;

(iv) Reduced installed horsepower of engines and operating speed; and

(v) Use alternative energy sources, for example, wind power.

Outboard motors used in small-scale fisheries are principally designed for the leisure market. These are lightly constructed, high revving, two-cycle engines with intricate electrical systems, requiring a high level of maintenance and spare part replacement. They are not designed for commercial operations and in the prevailing conditions of artisanal fisheries in developing countries, have a useful life of one to two years. Fuel consumption of the order of 0.425 kg/kWh and additional cost of two-cycle oil, were not serious constraints during the time of cheap energy. Spare parts were readily available before restrictions on foreign exchange were made. The convenience of outboard motors is such that they will never be completely replaced. The technology exists, however, to produce engines suitable for small-scale fishing operations, with long life, good specific fuel consumption, and the durability necessary to survive in working conditions.

An alternative to the outboard is the small diesel engine which is more fuel-efficient and durable than present outboards. Problems such as higher initial expenditure, increased weight, protection of an engine against swamping in beach landing craft and the difficulty of fitting propeller and stern gear for these conditions, can be overcome. One Food and Agriculture Organization (FAO) project in the Bay of Bengal is gaining acceptance for an inexpensive low horsepower engine of this type, totally enclosed in a pivoting engine box with incorporated stern gear, propeller and rudder. This engine can realize fuel economies of the order of 50 per cent over the equivalent outboard powered craft. In the European Economic Community (EEC) in Sierra Leone for Kambia Fisheries Development, MacAlister Elliott and Partners are carrying out comparative trials between inboard diesels and outboards in the 20-meter traditional canoes. In cash terms, the diesel boats consume less than a quarter as much for fuel, but not without some attendant problems.

With cheap and abundant fuel there has been little incentive to carry out careful matching of engines, stern gear and propeller. The tendency has been to increase horsepower progressively to the point where up to 30 to 40 per cent increases in fuel consumption resulted in speed increases measured in fractions of a knot.

In a number of fisheries projects in developing countries, considerable attention is being paid to fuel costs, and it would appear that the most immediate results in fuel saving can be expected from a combination of reductions in the installed horsepower of engines and operating speeds, together with the use of alternative energy sources, such as wind power.

Probably the most significant fuel saving in small fishing craft can be achieved by a reduction in operating speed, that is a reduction in utilized ship per ton of displacement (always provided that an appropriate propeller is fitted for the reduced operating horsepower and engine revolutions). Recent fuel consumption trials of an 8.7 meter inshore fishing craft with a 30 bhp engine indicate that a one-knot reduction in speed from 7.0 to 6.0 knots for this craft resulted in a reduction from 6.0 horsepower per utilized ton of displacement to 2.6 horsepower, and a reduction in fuel consumption of about 50 per cent. Actual fuel consumption in liters per hour dropped from 6.5 to 2.4. While this sort of saving can be expected in small craft operating near their maximum hull speed, such savings in fuel costs do not take account of the cost of increased voyage time, possible reduction in fish prices for later arrival in port, nor the human reaction of a fisherman not wishing to see his contemporaries pass him at a knot better operating speed.

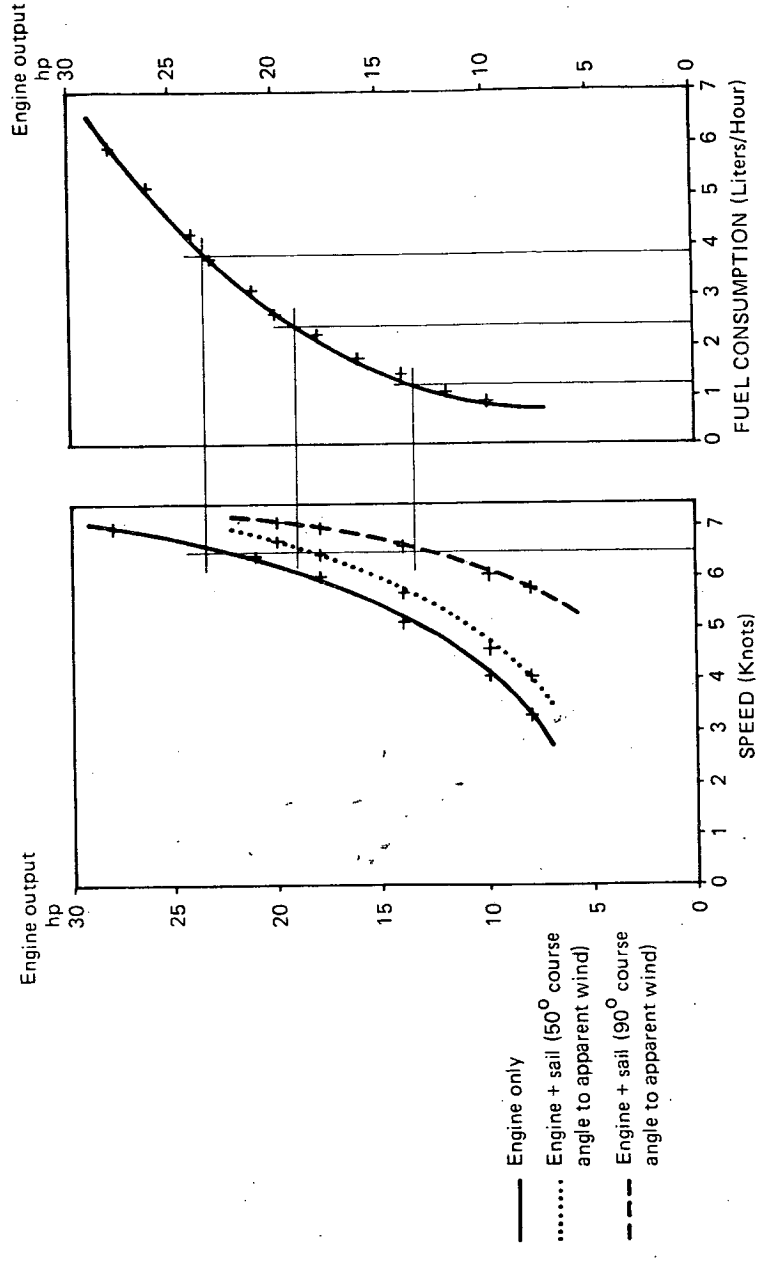
One solution to this latter problem is the use of combined sail and engine power to produce equivalent speeds at substantial fuel saving. For this particular vessel it was possible to demonstrate that the use of 24 sq m of sail in a 15-knot true wind, using approximately 60 per cent of available engine horsepower, gave an operating speed of 7.0 knots at an apparent wind angle of 90 degrees and 6.5 knots at an angle of 50 degrees (see Figure 1).

From this figure it can be seen that at an average operating speed of 6.5 knots, fuel consumption is 2.8 liters per hour under engine alone, 2.4 liters per hour using reduced engine power plus sail at a course angle of 50 degrees to the apparent wind (close hauled) and 1.25 liters per hour at an angle of 90 degrees to the apparent wind (reaching).

Until the turn of the century, all ocean transport was sail-powered, so it is natural to reintroduce sail as a means of propulsion to reduce fuel consumption. At the end of the era of sail, vessels, techniques and specialization were very highly developed, even though industrial technology was relatively primitive. In the industrialized countries, since the coming of steam until very recently, sail development has been confined to recreational craft.

Figure 1

Estimation of Fuel Consumption Using Various Combinations of Engine and Sail Power for an 8.5m (28ft) Fishing Boat in Somalia



Thus, most of the traditional skills for handling transport ships and fishing vessels under sail have been lost. Furthermore, in the developing world, sailing as a means of propulsion for fishing craft has declined in recent years and is underutilized in many areas despite favorable winds. In some areas, such as the northeast Indian Ocean, the China Sea and Malaysia, seafaring populations have developed sailing methods and use sail for much of the time. However, large parts of Africa, Indonesia and Central and South America, have not developed sails for their craft through lack of suitable materials, information and motivation.

Wind patterns in the tropics are generally stable and predictable with large areas benefiting from regular trade winds. In areas where sailing has been developed, suitable combinations of hull and rig have evolved. However, their development is considerably less advanced than the sophistication achieved by the north European and American sailing fishing fleets in the early 20th century. Some reasons for the lack of continued development of sail in developing nations are not hard to find. Many hulls are not strong enough to take the strains imposed by a sailing rig. Materials suitable for making efficient sails have only recently become available with the increasing use of machines to weave local cottons tightly enough to be of adequate density and strength. Many countries do not have suitable trees for long, straight spars, so that sailing rigs with short masts and spars made up of several pieces lashed to form a long length, have evolved.

Specialists working in the field of sail development have the advantage of an overview of rigs and techniques on a worldwide basis, plus experience of modern materials and technology. This enables a new approach to the design of sailing equipment for a traditional fishery within the economic and geographical constraints of the region. Ideally, this means using locally available materials, even though some of the materials may not have been used before for sailing (for example, galvanized wire rope). The economy of the fishery may justify importing some items such as fastenings, or nylon thread, which, although of minor importance in total cost, can make surprising improvements to the efficiency of the vessel and rig.

The aim must be to develop an acceptable appropriate sailing system which causes worthwhile fuel savings and which is sufficiently convenient and inexpensive for the fisherman to adopt spontaneously. Many artisanal fishing craft will sail without making substantial alterations. Almost any hull will run before the wind or broad reach. Most hulls will beam reach without appreciable leeway. To sail to windward requires a hull form with reasonably fine underwater lines and adequate lateral plane. In some small craft, this can be achieved by the addition of leeboards or center boards.

A study of the fishery in which a craft is operating, hull form and materials locally available for rig manufacture, will enable an appropriate

sailing rig to be designed. In some cases, it will be possible to design a sailing rig as primary propulsion. More often, the rig will be an auxiliary propulsion system, particularly when passages to windward are required. When motor sailing to windward, the lift coefficient of the hull and appendages is less critical, as the engine can provide much of the necessary windward component.

In all cases, the use of engines will be necessary to maintain fish production levels. Project experience has shown that fishing under sail alone rarely allows the same level of fishing effort as achieved under engine power in the time of cheap fuel. As can be seen from Figure 1, the most significant contribution of appropriate, locally produced sailing rigs is in the context of motor-sailing, where reductions in engine hours of up to 50 per cent have been recorded while maintaining previous levels of fishing achievement.

A sailing rig for small fishing craft should be:

(i) constructed from materials which are available locally or can be reasonably obtained;

(ii) convenient and easy to handle, and not obstruct fishing operations;

(iii) easily and effectively reduced (reefed) so that fishing operations can be carried out in varying weather conditions;

(iv) capable of working reasonably close to the wind;

(v) sufficiently attractive to fishermen as a means of efficient propulsion, while ensuring the maximum possible safety for the vessel; and

(vi) suitable for stepping and unshipping at sea on craft meant for surf and open beach landings.

PROJECT EXPERIENCE

MacAlister Elliott and Partners have participated in many sail development projects both for fishing and transport craft. Geographically, these projects have been in the Pacific, the Far East, India and Bangladesh, and several African countries. Many of these fisheries projects have been part of the FAO's continuing program of artisanal fisheries development. Gifford and Partners have also undertaken sail projects in India and Sri Lanka and have carried out a research program on sail/hull interactions for the European Development Fund. MacAlister Elliott and Partners and Gifford and

Partners plan to start a joint research project in the near future, making use of their combined research findings.

The aim of all these projects is to assist small-scale fishermen to develop sailing rigs from their own resources, rigs which will suit their fishing methods and contribute to the propulsion of their craft. On these projects, tailors and local artisans are trained in the techniques of making improved sails, and in the use of synthetic fiber ropes and wire for running and standing rigging. The completed sailing rigs are also demonstrated to fishermen in authentic fishing conditions and changes in fishing methods, if required, are identified and introduced. Boats are built, modified, and strengthened, as required, to accommodate the rigs.

Many small-scale fishing communities have developed their fishery beyond the fishing practices of past generations. Motorization has given them a degree of independence from the previous restrictions of currents and wind. The urge for speed and increasing amounts of horsepower is a very natural human reaction, and it is often difficult to promote sail as it is considered retrogressive. In many cases, a generation has grown up without the knowledge of seamanship required to operate fishing craft under sail and the skills have been lost.

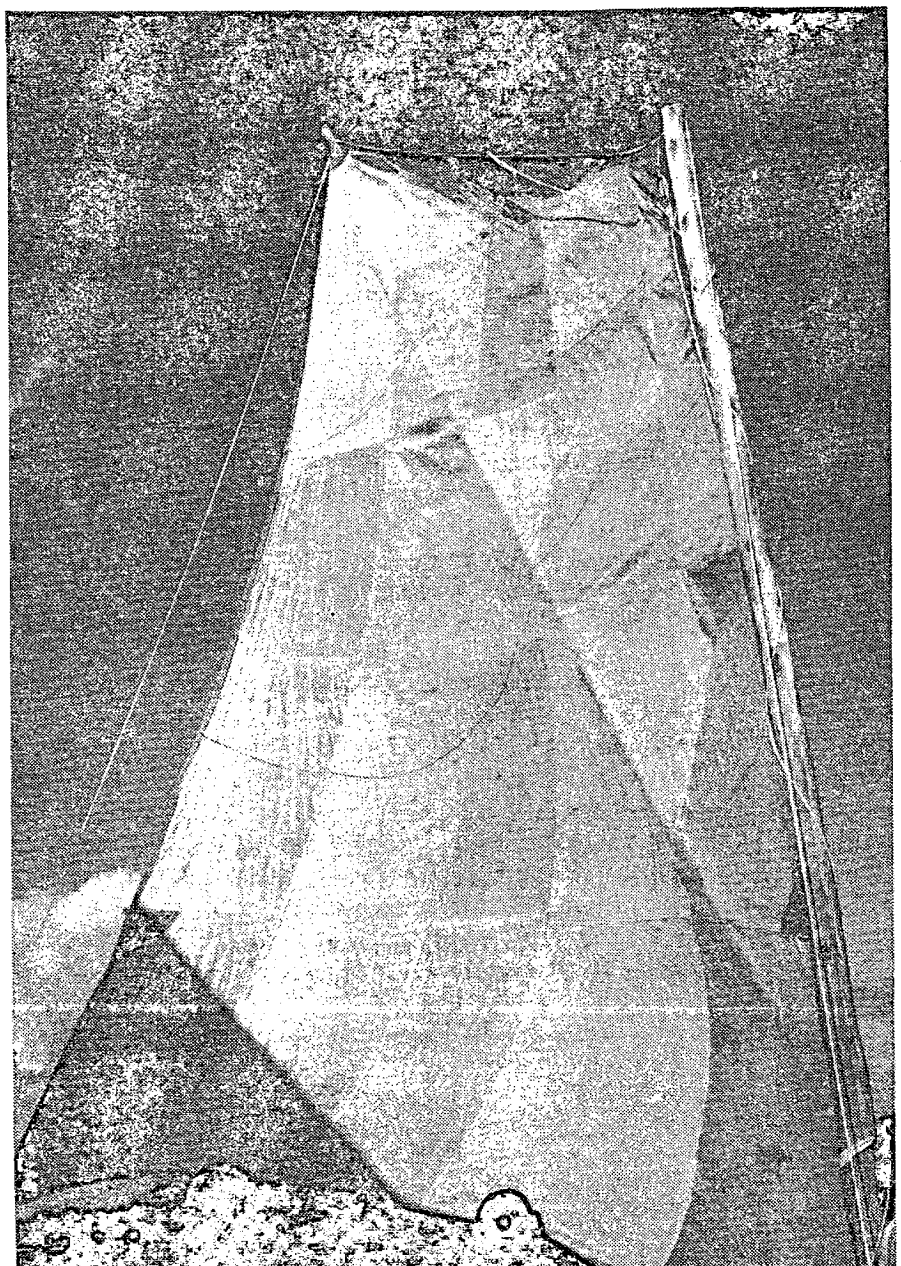
Project experience has shown that, in countries where fuel has become unavailable for long periods and effort has been severely curtailed, fishermen are willing to learn and to apply the seamanship required to sail their craft. However, in countries where fishing with engine power is still possible, no matter how rapid the decline in profitability in recent years, fishermen resist efforts to introduce primary or auxiliary sailing systems, unless the introduction is carried out with appropriate education and training. The efficiency and convenience of the rig and sail-motor balance is therefore critical for acceptance. Early experience in training programs for fishermen has been encouraging. Fishermen are making continuous use of sailing rigs; for example, at Cacheu in northern Guinea Bissau, they have convinced their colleagues of the benefits by demonstration. However, initial education was necessary to establish the techniques of utilizing the sailing rigs to best advantage.

The following descriptions and plates give a cross section of typical projects.

(a) Inland Fisheries Development, Zambia

Lake Mweru in the North West of Zambia supports an extensive artisanal fishery. Much of the catch is taken from the inshore area of the lake and is threatening the juvenile and breeding stock. The Swedish Board of Fisheries is supporting a project to improve fishing craft and propulsion,

Plate 1



Locally Available Sack Material Used as Sails in Zambia

and to encourage fishing further into the lake. In April 1985, a MacAlister Elliott and Partners team started at Nchelenge on Lake Mweru. Together with other activities, sails were introduced and demonstrated with continued success.

(b) Sail Development Project, Somalia

The artisanal fishery of the Indian Ocean coast of Somalia is carried out in traditional *houris* (dug-out canoes), of between six and nine meters in length, and in recently supplied fiberglass motor fishing vessels of similar length. Due to the rapid fuel price rises of the 1970s, their economic viability has been seriously compromised. In consequence, the development or re-introduction of efficient sailing rigs to reduce fuel energy consumption in small-scale operations has become important in restoring a favorable economic return to the fishermen.

A Principal of MacAlister Elliott and Partners was attached to the FAO Small-Scale Fishery Development Project at Kismayo in Southern Somalia. Local staff for the Project were trained in the techniques of sail making, spar making and preparation of running and standing rigging. Sailing rigs were installed and sailing trials carried out on the fishing craft to determine the possible fuel savings available from the use of sailing rigs constructed from local materials.

(c) Sierra Leone

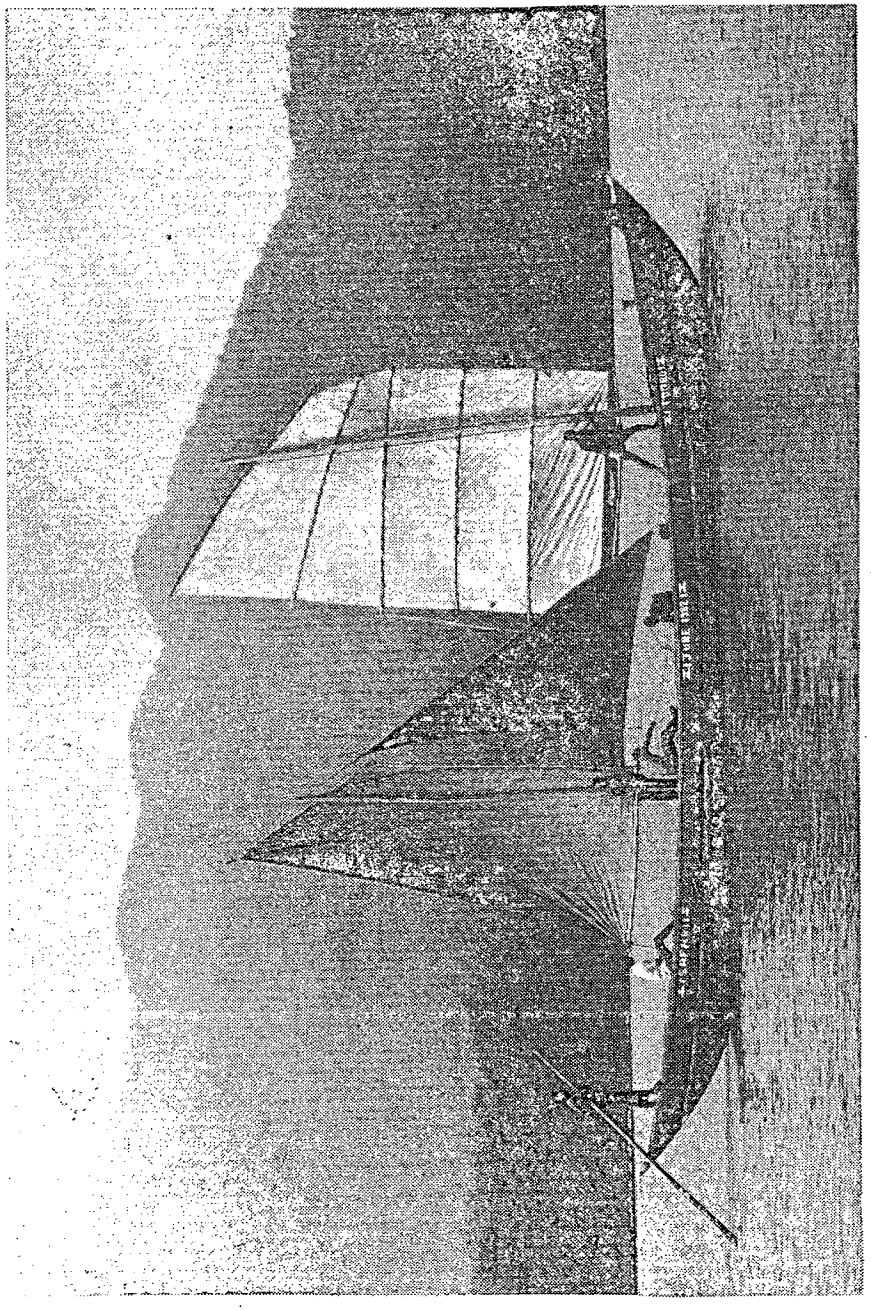
The FAO has provided technical assistance to a fisheries pilot project at Tombo, Sierra Leone. The fishery is based on the use of large Ghana planked canoes of up to 20 meters in length and smaller *Bonga* boats. A number of rigs have been successfully demonstrated with the smaller *Bonga* boat rig being used for the mizzen sail on the Ghana plank boat.

(d) Bay of Bengal Sail Trials

Although much research has been done on western competitive sailing rigs, little comparable information has been available until recently for the traditional rigs used in many thousands of fishing communities.

The FAO Bay of Bengal Programme (BOBP), already involved with FAO sail development, set up a series of instrumented sailing trials at Madras, aimed to gain a better understanding of the relative merits of various sailing rigs. Steve Akester of MacAlister Elliott and Partners Ltd. and Alan Boswell joined the BOBP team to organize the trials. To ensure that true comparisons could be made, two identical boats were produced and rigs

Plate 2



Ghana Plank Boat, Demonstrating lug mizzen sail and junk mainsail

and sails manufactured at the sail loft set up for the BOBP by MacAlister Elliott and Partners' sailmaker, John McKillop. It was decided to build two identical boats in fiberglass and the IND-20 design was selected, a 8.5 meter beachboat developed for Andhra Pradesh. The vessels were equipped with a fiberglass center board and rudder using an aircraft wing NACA 0012 profile, both of which were fitted off center. Universal mast steps and chainplates to enable any of the masts to be accepted, stayed or unstayed, were fitted to the boats. For ballast, 50 kg sandbags were used, securely stowed inside the hold. Since the propeller and motoring rudder on the beachboats could be lifted out of the water, their sailing performance was good.

Each test rig had a total sail area of 27 sq m. Manufacturing and cost details were recorded as shown in Table 1.

Table 1
Cost of 27 Sq M Rigs Used in the Trials

Rig	Cost of Materials ($)				Weight (kg)			Labor Manhours			Total cost in India
	Sails	Rigging	Spars	Total	Sails & Rigging	Spars	Total	Sails	Rigging	Total	$[c]
Bermuda	106	50[a]	108[b]	264	21	31	52	11	8	19	362[b]
Dipping Lug	105	6	3	114	21	47	68	9	3	12	160
Gunter	106	25[a]	3	134	21.5	52.5	74	12	8	20	194
Lanteen	103	7	5	115	21	47	68	8	3	11	160
Junk	105	16	10	131	55	85	140	12	10	22	192
Sprit	106	27[a]	3	136	47.5	69	69	12	8	20	197

a Stainless steel wire standing rigging.
b Aluminum mast and boom.
c Based on 30 per cent overhead cost on materials, $1.00 per manhour for labor, including overhead.

Although conditions varied, tests were carried out for each rig in fresh winds and reasonable sea conditions. Wind speed and direction were measured by a cup anemometer and vane mounted on a pole in the bow of the boat. Water speed was measured by a towed spinner type electrical log. Both wind and water speed were averaged over intervals of four seconds. An observer averaged the wind direction. An attempt was made to measure leeway with a pointer attached to the log line, but the movement of the

boat in the seaway was too vigorous to allow accurate measurement of the small angles involved, so leeway was estimated by the observers and generally assumed to be five degrees when sailing upwind and zero off the wind. This did not seem to affect the accuracy of the results as much as the problem of obtaining measurements in the unsteady wind and waves.

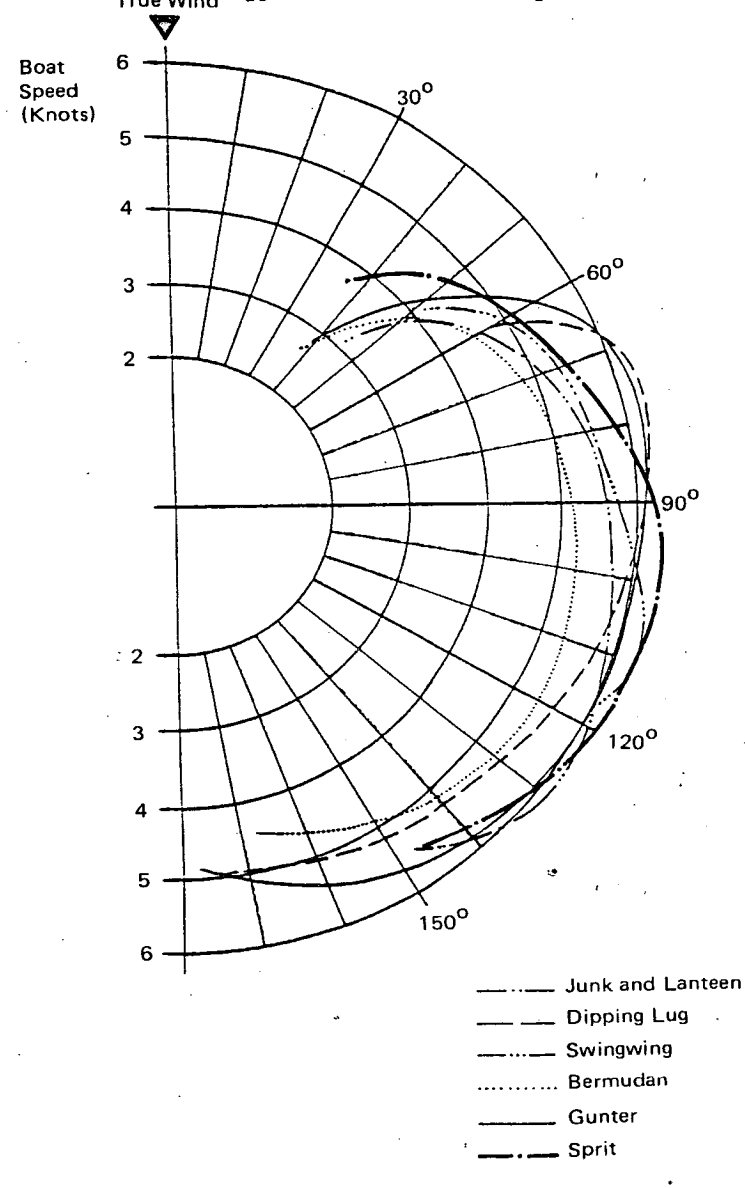
Predictably, a large amount of scattered data resulted from the tests. The data points were first plotted on a polar grid representing true wind angle and boat speed. True wind speed was written next to each data point to permit interpolation to a standard true wind speed, chosen as 13 knots because most of the rigs had data points close to or spanning this speed. This enabled standardized polar diagrams to be produced for each rig with some level of confidence. Nevertheless, the accuracy of the results was affected by two factors. The combination of rapidly changing wind speed and waves of a significant height relative to the size of the boat, meant that it was very difficult to obtain consistent results, even with wind and water speed meters taking averaged readings and the observers trying hard to make measurements only in short periods when the wind was not obviously gusting or dropping. For purposes of comparison, the performance of each rig at a true wind speed of 13 knots was interpolated from the data obtained. Had more time been available, results covering a wider range of wind speeds could have been obtained. Most of the time the wind speeds were such that the hull was usually at or close to its top speed of approximately 6.5 knots, where large changes in driving force from the rig only produce small changes in speed.

Summary of Results in Bay of Bengal Trials

The superimposed polar diagrams for all the rigs adjusted to 13 knots true wind speed (see Figure 2) support the conclusions reached in competitive trials that the gunter, sprit and dipping lug performed best on the wind. The relatively poor windward performance of the lanteen and Bermudan rigs was at first sight surprising, but study of the individual plots of all the data reveals that the latter rigs were obliged to reduce sail area in response to strengthening winds by reefing earlier than the other rigs. In other words, they produced more heeling and side force for a given amount of drive than the lower aspect ratio rigs. This would not only cause more heel in a given wind strength, but also more leeway, which would further adversely affect windward performance. To optimize the Bermudan rig, therefore, one needs a stiff boat and rig. All the rigs appeared to have similar performance off the wind. At the wind speeds in which most of the measurements were made, the resistance of the boats climbed rapidly as a hull speed of about 6.5 knots was approached.

Figure 2

Polar Performance Curves in 13 Knots True Wind Speed



Looking at the performance of the three best rigs in more detail, one is struck by the curious shape of the polar diagram for the sprit rig. It appears to have a pronounced peak very close to the wind at about 45 degrees, and then a plateau from 55 degrees to 80 degrees where the gunter and dipping lug perform better. The sprit appears to peak again around 90 degrees before falling back to match the others off the wind.

To summarize, the gunter, dipping lug and sprit rigs all performed better than the traditional lanteen, and were also far easier to handle, allowing good progress to be made upwind even in narrow channels. The junk rig performed as well, or better, than the lanteen in the conditions of the trials, and was easier to handle. The Bermudan rig showed up poorly as it appeared to generate far more heeling force relative to drive than the other rigs. It is conceivable, however, that the lanteen and Bermudan rigs would have performed better in very light conditions. In general, these results compare closely with the sail performance analysis carried out subsequently by Professor Marchaj with MacAlister Elliott and Partners Ltd. and the Overseas Development Authority.[1]

CONCLUSIONS

Many subsistence and artisanal fisheries will benefit from the introduction of appropriate sailing rigs, either for primary or auxiliary propulsion. In some situations, however, the introduction of sailing rigs would not be justified; fuel saving efforts should focus on improving the efficiency of mechanical power installed and on showing operators how to use it intelligently.

The introduction of sailing rigs to a fishery requires careful study and design work, followed by technical assistance to: (i) train artisans in the skills of sailing rig construction; (ii) boatbuilders in the techniques of installing sailing rigs and the necessary construction improvements; and (iii) fishermen in the use of the rigs to best advantage.

Experience to date has shown that these principles can reactivate fishing effort in economically deprived fishing communities. Efforts must continue to devise appropriate and acceptable sailing rigs for developing countries and to train fishermen in their use.

1 See Mr. Marchaj's Conference paper, Planform Effect of a Number of Rigs on Sail Power.

REFERENCES

1. Akester, S. J. and J. F. Fyson, "Appropriate Sailing Rigs for Artisanal Fishing Craft in Developing Nations", Food and Agriculture Organization, Rome.

2. Fyson, J. F., "The Use of Sail-Engine Power Combinations for the Saving of Fuel-Energy in Small Fishing Craft", Royal Institute of Naval Architects Conference on Propulsion for Small Craft, 1982.

3. Fyson, J. F. and S. J. Akester, "Demonstration of the Use of Sail Power in Small Fishing Vessels", Food and Agriculture Report to the Government of Somalia, 1982.

4. Fyson, J. F., "The Use of Sail Power in Fishing Vessels", South Pacific Commission, Thirteenth Regional Technical Meeting on Fisheries, 1981.

The International Maritime Organization's Interest in Sail-Assisted Technology

S. Badendyck*

INTRODUCTION

The International Maritime Organization's (IMO) mandate stems from the need to spread safety resources and standards uniformly across all the world's fleets and waters to cope with the ever increasing sophistication of technology in its various marine applications and to preserve the marine environment.

The safety legislation emanating from IMO provides national maritime administrations with a basis from which to develop a coordinated maritime safety control policy which responds, on the one hand, to pressure from within the maritime industry to improve standards of operation and maintenance and, on the other, to international requirements.

Concern for operational safety in the performance of tasks involving technically complex machinery, or newly tested ideas such as the sail-assisted vessel technology, brings out the importance of both safety design and human factors.

The current energy situation, with nonrenewable oil resources, high ship operational costs and policies for protection of the environment, will make the reintroduction of wind power as an auxiliary source of propulsion, after many decades, a very attractive proposition for sea-going vessels. As indicated by the many studies carried out to date, the use of wind as a complementary source of energy in the shipping sector will likely be increasingly introduced in the future, for the benefit of developed and developing countries alike. Wind-powered vessels are now, after the research stage, at an incipient stage of commercial exploitation.

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* Captain Badendyck represents the IMO in the ASEAN countries. He is an Extra Master Mariner. His main field of work involves maritime search and rescue and antipiracy.

Related to this likely development is the subject of safety (and consequently insurance costs) which will obviously affect the attitudes of decision makers, including governments, shipowners, ship operators and users.

In general terms, safety at sea stands on two main factors: structurally sound ships and well trained crews. The structural factor depends on the type of hull, stability features, types of sails and rigging, superstructure design as well as on the type of cargo and geographical area of operation. In terms of crew training, there is an acute lack of trained personnel in the use of wind-powered vessels, since the system was abandoned decades ago. This may be particularly important insofar as ship officers are concerned, since sailing on similar ships for a given period is usually a prerequisite for obtaining a master's license.

When life and heavy investments are at stake, extreme caution is necessary and this is true both for the state and private shipping sectors. The safety aspect in shipping must be emphasized due to the fact that, while IMO provides member governments with the necessary guidelines on safety, it is the ultimate responsibility of the governments, through their administration, to legislate and regulate practice for the implementation of safety conventions.

A POSSIBLE ROLE FOR IMO

IMO has not yet devoted itself to an in-depth study of safety aspects associated with sail-assisted vessels. Neither are these aspects reflected in the immediate future work program of IMO. It is, consequently, not presently clear how the different national administrations and the ship classification societies would react at the time of issuing the seaworthiness, load line and safety certificates, etc. for a sail-assisted commercial vessel. Nevertheless, it would eventually be up to IMO to evaluate the sail-assisted vessel from the point of view of safety matters in relation to IMO conventions.

If the vessels concerned are cargo ships of over 500 gross registered tons, requirements of the Safety of Life at Sea (SOLAS) Convention are applicable. The main problem in relation to safety may be the stability of the ship, and at present there are no IMO requirements exclusively for sailing ships. Resolution A.167(ES/IV) gives no guidance with respect to such types of vessels. It seems obvious, however, that the fitting of sails with extremely high windage areas must influence stability calculations, taking into account extreme heeling moments. Thus, suitable methods for compensation of listing have to be devised, other than moving ballast across from one side of a vessel to the other.

Another aspect related to safety is maneuverability. When powered by its engines the sail-assisted vessel may be maneuvered normally. However, when powered by sails only (and this may be an extreme situation) maneuverability might be a serious problem, particularly in crowded waters. To this should be added the adverse effect of reduced visibility caused by low navigation bridges and sail surfaces.

Also, the question of manning should not be underestimated. It would not be quite correct to assume that an automated sail-assisted ship would need the same crew as an automated motor vessel of equivalent features, due to obvious safety aspects such as failure of rigging/sails, or the automated mechanism.

Another aspect to consider, even if it is of secondary importance, is cargo handling, particularly during cargo discharge. For certain cargo the mast and sail rigging can make cargo operations cumbersome and risky, even if the mast and rigging play a role in supporting the cargo derrick, and the sail-boom acts as the cargo derrick itself.

With these reflections, to cite a few, I have tried to convey the genuine interest of the IMO in all work related to sail-assisted vessels.

CONCLUSIONS

To conclude, it may be stated that the interest of IMO in a particular subject only reflects the interest of its member states in such a subject.

It can also be said, based on recent history, that international attention (and therefore action through IMO) to safety issues appears in the aftermath of a maritime accident.

It is earnestly hoped that this does not happen with sail-assisted vessels and that scrupulous compliance with the existing IMO international conventions will provide the shipping world with the necessary confidence for the commercial exploitation of sail-assisted vessels on cleaner oceans.

REFERENCES

A list of technical resolutions generally relevant to this work is as follows:

Intact Stability of Fishing Vessels (A.88(IV))

Amendments to Chapter II of the International Convention for the Safety of Life at Sea, 1960 (supplemented by A.109, A.110, A.124, A.276) (A.108(ES.III))

Amendments to the International Convention for the Safety of Life at Sea, 1960 (A.122(V))

International Conference on Load Lines, 1966 (A.133(V))

Amendments to the International Convention for the Safety of Life at Sea, 1960 (A.146(ES.IV))

Recommendation on Data Concerning Maneuvering Capabilities and Stopping Distances of Ships (supplemented by A.209(VII)) (A.160(ES.IV))

Recommendation on Intact Stability for Passenger and Cargo Ships under 100 meters in Length (amended by A.206, supplemented by A.287) (A.167(ES.IV))

Recommendation on Intact Stability of Fishing Vessels (supplemented by A.208, A.267, A.268, A.269) (A.168(ES.IV))

Amendments to the International Convention for the Safety of Life at Sea, 1960 (A.174(VI))

Amendments to the International Convention for the Safety of Life at Sea, 1960 (supplemented by A.284, A.378) (A.205(VII))

Recommendation on Construction of Fishing Vessels Affecting the Vessel's Stability and Crew Safety (A.208(VII))

Amendments to the International Convention on Load Lines, 1966 (supplemented by A.319) (A.231(VII))

Amendments to Chapters II, III, IV and V of the International Convention for the Safety of Life at Sea, 1960 (supplemented by A.270, A.332) (A.263(VIII))

Regulations on Subdivision and Stability of Passenger Ships as an Equivalent to Part B of Chapter II of the International Convention for the Safety of Life at Sea, 1960 (supplemented by A.266) (A.265(VIII))

Amendments to Recommendation on Intact Stability of Fishing Vessels, Appendix V - Recommended Practice on Portable Fish-hold Divisions (A.168) (A.268(VIII))

Procedures for the Control of Ships under the International Convention for the Safety of Life at Sea, 1960 and the International Convention on Load Lines, 1966 (supplemented by A.442, A.466) (A.390(X))

Ratification of the 1975 Amendments to the International Convention on Load Lines, 1966 (A.410(XI))

Amendment to the International Convention on Load Lines, 1966. Annex Amendment to the International Convention on Load Lines, 1966 (A.411(XI))

Acceptance and enforcement of international instruments relating to maritime safety and marine environment protection (A.412(XI))

Guidelines on surveys and inspections under the Protocol of 1978 relating to the International Convention for the Safety of Life at Sea, 1974 and under the Protocol of 1978 relating to the International Convention for the Prevention of Pollution from Ships, 1963 (supplemented by A.465)

Annex: Guidelines on Mandatory Annual Surveys, Unscheduled Inspections of All Cargo Ships as well as Intermediate Surveys of Tankers of Ten Years of Age and Over under the Protocol of 1978 relating to the International Convention for the Safety of Life at Sea, 1974 (A.413(XI))

Code on Noise Levels on Board Ships (A.467(XII))

Amendments to the International Convention on Load Lines, 1966 (A.513(XIII))

Amendments to the regulation equivalent to regulation 27 of the International Convention on Load Lines, 1966 (amends A.320) (A.514(XIII))

Future amendments to the International Convention for the Safety of Life at Sea, 1974 (A.515(XIII))

APPENDICES

ASIAN DEVELOPMENT BANK

REGIONAL CONFERENCE ON SAIL-MOTOR PROPULSION

MANILA

18 - 21 NOVEMBER 1985

CONFERENCE PROGRAM

Monday, 18 November

0900-1000	Registration	—	Secretariat
1000-1005	Introduction of Chairman	—	Mr. John Brooks Shipping Specialist Asian Development Bank
1005-1015	Conference Introduction	—	Chairman Mr. Suleman Wiriadidjaja (Indonesia)
1015-1030	Keynote Address	—	Mr. Günther Schulz Vice-President (Projects) Asian Development Bank
T E A			
1045-1200	Overview	—	Dr. C. J. Satchwell (United Kingdom)
L U N C H			
1330-1445	Developing Techniques in Sail Assistance - *French Experiments* -	—	Mr. J. Constans (France)
T E A			
1500-1630	Modern Sail Design	—	Mr. C. A. Marchaj (United Kingdom)

TEA

1500-1630	Modern Sail Design	—	Mr. C. A. Marchaj (United Kingdom)
1700-1900	Cocktail Reception *Headquarters Building Asian Development Bank*	—	Mr. S.V.S. Juneja Director Infrastructure Dept. Asian Development Bank

Tuesday, 19 November

0900-1030	Developing Techniques in Sail Assistance *Japanese Developments in Sail Assistance and Ship Design Features in Marine Fuel Savings*	—	Dr. N. Hamada (Japan)

TEA

1045-1200	Tongan Feasibility Study for Interisland Sail	—	Mr. C. Palmer and Capt. E. Corten UN-ESCAP, Bangkok

LUNCH

1330-1445	Government of Fiji/ADB Sail Retrofit Experiments	—	Mr. R. G. MacAlister and Capt. R. Maharaj

TEA

1500-1600	Wind Routing Principles and Applications for Interisland Shipping	—	Dr. J. Mays (USA)
1600-1700	Problems in Interisland Transport		Prof. H. C. Brookfield (Australia)
1730-1900	Film Show on Sail Motor Projects	—	Dr. N. Hamada/ Capt. E. Corten

Wednesday, 20 November

0900-1030	Indonesia's INDOSAIL Project	—	Mr. Suleman Wiriadidjaja (Indonesia) and Mr. P. Schenzle (Fed. Rep. of Germany)

TEA

1045-1200	Ship Management, Training and Management in Sail Assistance	—	Prof. J. King (United Kingdom)

LUNCH

1330-1445	Application of Sail for Inland Waterways	—	Admiral M. H. Khan and Dr. Mahiuddin Chowdhury (Bangladesh)

TEA

1500-1600	Use of Models in Marine Energy Savings Project	—	Dr. C. J. Satchwell (United Kingdom)
1600-1700	Application of Sail in Fisheries Development	—	Mr. R. G. MacAlister (United Kingdom)
1730-1930	Film Show on Sail-Motor Projects	—	Mr. J. Constans Mr. Baharuddin Abidin Mr. C. Palmer

Thursday, 21 November

0915-0945	Compatibility of New Techniques in Sail with Present Interisland Shipping Practice in Asia/Pacific Region	—	Mr. Marah S.M. Harahap (Indonesia)

TEA

1000-1230	Workshop		

LUNCH

1400-1500	Workshop, Conclusions on Future Regional Applications of Sail		

TEA

1515-1545	Concluding Remarks	—	Mr. Suleman Wiriadidjaja (Indonesia)

CONFERENCE ATTENDANCE

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(a) Asian Development Bank Loan Projects in the Ports and Shipping Sector (1973-1985)

Country	Loan No.	Project Name	Amount ($million)	Source[a] of Fund	Date of Approval
Bangladesh	143	Chittagong Port	3.200	SF	18 Oct 73
	144	Chittagong Port	3.600	OCR	18 Oct 73
Burma	456	Outports	15.500	SF	10 Jun 80
Fiji	411	Suva Ports	7.000	OCR	20 Sep 79
Indonesia	91	Tandjung Priok Port Development	5.300	SF	4 Apr 72
	103	Surabaya Port Development	5.500	SF	24 Oct 72
	245	Belawan & Surabaya Phase I	4.350	OCR	2 Dec 75
	317	Fourth Port	17.500	OCR	17 Nov 77
	375	Fifth Port	26.300	OCR	7 Dec 78
	595	Sixth Port	5.400	OCR	4 Nov 82
	688	Seventh Port	86.000	OCR	28 Aug 84
Kiribati	281	Causeway	1.750	SF	18 Nov 76
	724	Betio Shipyard Rehabilitation	0.550	SF	13 Dec 84
Korea	133	Incheon Port Development	16.300	OCR	26 Jun 73
	458	Second Incheon Port Development	54.000	OCR	26 Jun 80
Malaysia	18	Kuching Port Expansion	5.000	OCR	13 Nov 69
	47	Sibu Port Expansion	3.500	OCR	10 Dec 70
	147	Kuantan Port	30.400	OCR	8 Nov 73
	184	Penang Port Expansion	15.100	OCR	18 Apr 74
	296	Second Penang Port Expansion	10.000	OCR	29 Mar 77
	426	Bintulu Deepwater Port	53.800	OCR	23 Nov 79
	689	Third Penang Port Expansion	45.800	OCR	28 Aug 84
Pakistan	279	Port Qasim	37.800	OCR	18 Nov 76
	280	Port Qasim	10.800	SF	18 Nov 76
Papua New Guinea	468	Lae Port	12.000	OCR	25 Sep 80
	469	Lae Port	8.000	SF	25 Sep 80
	738	Ports Development	11.000	OCR	2 Jul 85
Philippines	61	Fisheries Port	1.000	SF	4 Mar 71
	62	Fisheries Port	4.500	OCR	4 Mar 71
	126	Cotabato Port Development	6.600	OCR	3 Apr 73
	412	Manila Port	27.000	OCR	27 Sep 79
Singapore	35	Jurong Wharves Expansion	8.310	OCR	3 Sep 70
	73	Singapore Port Expansion & Warehousing	8.100	OCR	2 Sep 71
Sri Lanka	31	Colombo Port Tanker Berth	2.600	OCR	30 Mar 70
Solomon Is.	323	Honiara Port Development	2.030	SF	9 Dec 77
Taipei, China	22	Hualien Harbor Development	0.990	OCR	4 Dec 69
Thailand	355	Songkhla and Phuket Ports	1.500	OCR	21 Sep 78
	546	Songkhla and Phuket Ports	71.400	OCR	25 Nov 81
		Subtotal	$629.480		

a OCR = Ordinary Capital Resources; SF = Special Funds.

Country	Loan No.	Project Name	Amount ($million)	Source[a] of Fund	Date of Approval
Multiprojects					
Cook Is.	461	Multiproject	1.000	SF	21 Aug 80
Maldives	513	Interisland Transport & Shipping	1.000	SF	18 Jun 81
	681	Multiproject	2.380	SF	29 Mar 84
Tonga	435	Multiproject	1.200	SF	10 Dec 79
	540	Second Multiproject	1.680	SF	17 Nov 81
	782	Third Multiproject	2.000	SF	19 Jun 86
Vanuatu	766	Multiproject	3.000	SF	5 Dec 85
W. Samoa	752	Multiproject	4.000	SF	19 Nov 85
		Subtotal	$16.260		
		Grand total	$645.740		

a OCR = Ordinary Capital Resources; SF = Special Funds.

(b) Asian Development Bank Technical Assistance Projects in the Ports and Shipping Sector (1968-1986)[a]

Country	Project	Amount ($ Million)	Year Approved	Type of Technical Assistance[b]
Ports				
Philippines	Fisheries Port	0.325	1968	PP
Philippines	Fisheries Port	0.071	1971	A&O
Philippines	Cotabato Port	0.245	1971	PP
Indonesia	Financial Management of Ports	0.250	1972	A&O
Bangladesh	Feasibility Study of Port Expansion & Financial Management of Chittagong Port	0.160	1973	A&0
Indonesia	Ports Study	0.580	1973	PP
Indonesia	Belawan & Surabaya Ports (Phase II)	0.100	1975	PP
Thailand	Port Development	0.050	1976	PP
Solomon Islands	Port Tariff & Acctg/Mgt Study	0.050	1977	PP
Burma	Outports Improvement	0.250	1977	PP
Republic of Korea	Second Incheon Port	0.150	1978	PP
Indonesia	Belawan Port (Phase II)	0.150	1978	PP
Papua New Guinea	Lae Port Development	0.150	1979	PP
Indonesia	Sixth Port	0.150	1982	PP
Maldives	Multiproject	0.215	1984	A&O
Papua New Guinea	Management Information System Study	0.120	1985	A&O
Vanuatu	Appraisal of Subprojects under Multiproject Loan	0.270	1985	A&O
Solomon Islands	Second Honiara Port	0.075	1986	PP
Tonga	Appraisal of Subprojects under Third Multiproject Loan	0.221	1986	A&O
	Subtotal	3.582		
Shipping				
Kiribati	Inter-Island Shipping	0.050	1976	PP
Maldives	Inter-Island Transport and Related Telecommunications	0.098	1979	PP
Fiji	Experimental Study on Sail/Motor Propulsion	0.250	1983	A&O
Kiribati	Betio Shipyard Improvement	0.225	1983	PP
Fiji	Suva Shipyard Improvement	0.215	1983	PP
Bangladesh	Inter-Modal Transport Study	0.355	1984	A&O
Kiribati	Betio Shipyard Rehabilitation	0.290	1984	A&O

a As of 31 July 1986.
b PP = Project Preparation; A&O = Advisory and Operational.

Country	Project	Amount ($Million)	Year Approved	Type of Technical Assistance[a]
Papua New Guinea	Navigational Aids Improvement	0.240	1984	PP
Thailand	Bangkok Port Second Navigation Channel	0.150	1985	PP
Maldives	Inter-Island Transport Operation's Review	0.200	1985	A&O
Regional	Regional Conference on Sail-Motor Propulsion	0.175	1985	Regional
Kiribati	Betio Shipyard Improvement	0.060	1986	A&O
Thailand	Advisory Services for Harbour Department	0.200	1986	A&O
Kiribati	Betio Shipyard Improvement (Supplemental)	0.060	1986	A&O
	Subtotal	2.568		
	Grand Total	6.150		

a PP = Project Preparation; A & O = Advisory and Operational.